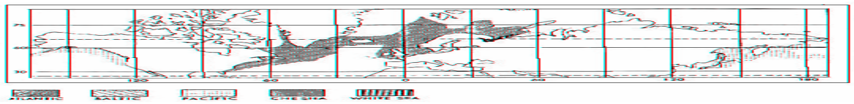


Chapter 3. ENVIRONMENTAL SETTING

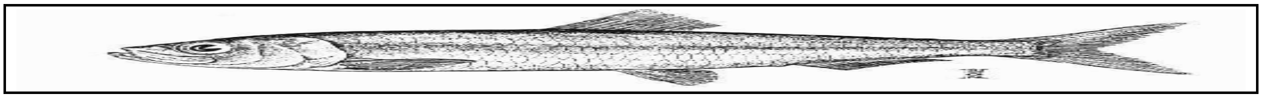
3.1 General

Herring are recognized as a fish species of worldwide importance (Blaxter 1985) and have been the subject of more research than any other fish (Blaxter and Holliday 1963). A brief overview is provided to delineate differences and similarities among herring groups found worldwide.

Historically, herring have been divided into five subgroups (Figure 3.1), generally considered to be five subspecies separated primarily by geography (Blaxter 1985). However, recent taxonomic literature has designated the Pacific herring a separate species (Robins et al. 1991, Grant 1986). The subgroups have different body characters (body dimension, size at first maturity, longest length, vertebral and other structure counts). The species subject to the proposed project is the Pacific herring (*Clupea pallasi*).

Pacific herring lay adhesive eggs on substrate (shell rubble, pier pilings) and vegetation in a wide range of open ocean environments (shallow subtidal to the intertidal zone) and in estuarine subtidal and intertidal zones. The other herring species to lay eggs on substrate in the open ocean is the Atlantic herring (*Clupea harengus*) (Blaxter and Hunter 1982).

All five subgroups of herring share a number of characters in common. For example, they all have the same silvery color pattern (blue-green above fading to silvery white below) which provides countershading and camouflage in mid-water; they exhibit a strong schooling behavior; and all can switch from particulate (biting) feeding to filter-feeding.



The herring family (Clupeidae) includes such closely related Pacific coast species as the Pacific sardine (*Sardinops sagax*) and the American shad (*Alosa sapidissima*).

3.2 General Biological and Environmental Descriptions

3.2.1 Life History

3.2.1.1 Taxonomy and Morphology

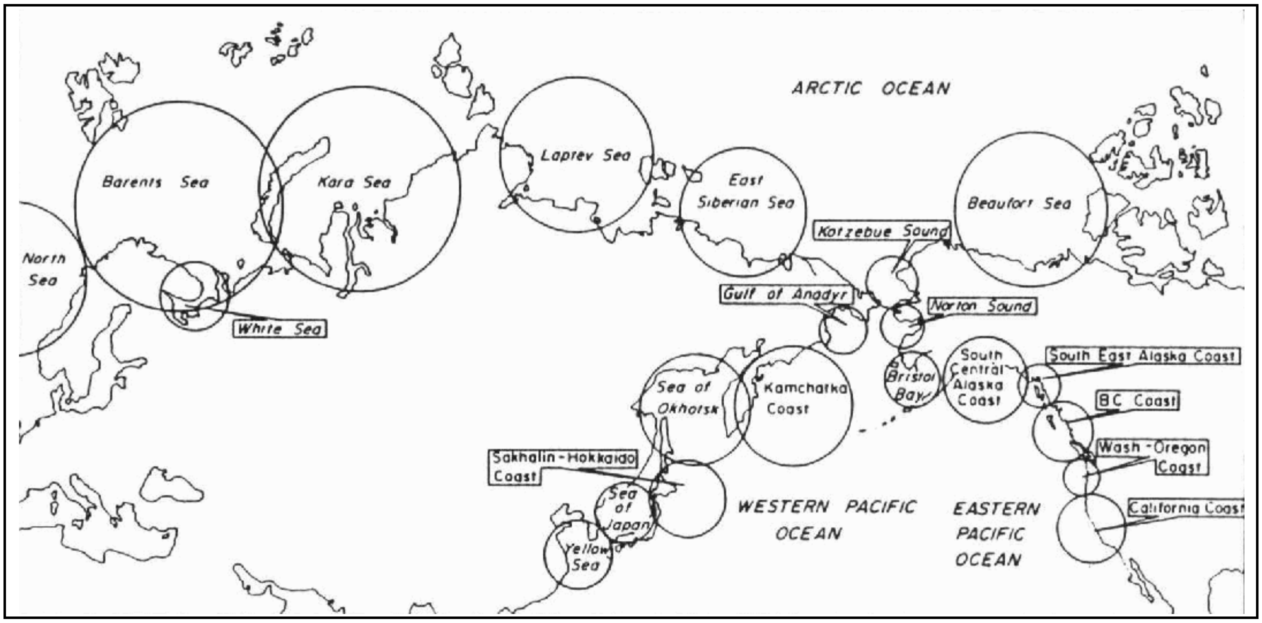
Scientific name .... *Clupea pallasi*
Class .... Osteichthyes
Order .... Clupeiformes
Family .... Clupeidae

Preferred common name .. Pacific herring
Other common name ...... Herring

Pacific herring are moderately compressed silvery fish with unspined fins (Barnhart 1988)(Figure 3.2). Their body color is dark bluish green to olive on the upper surface, shading to silver on the sides and belly. They have a short dorsal fin near the middle of the back, abdominal pelvic fins beneath the dorsal fin, and a deeply forked tail fin. They lack scales and striations on the head or gill covers, spots on the sides, lateral line canal, modified scales or flaps on the side of the tail fin, and teeth on the jaw (Eschmeyer et. al. 1983, Hart 1973).

3.2.1.2 Distribution and Migration

Herring, in general, are adapted to an open ocean pelagic habitat (Blaxter and Holliday 1963). Schooling behavior in Pacific herring develops well before metamorphosis from the larval to adult forms (Marliave 1980). Because Pacific herring schools use open ocean areas inshore of the continental shelf (coastal or neritic zone) for much of their life cycle and spawn in



shallow inshore areas, migrations are extensive (Outram and Humphreys 1974).

Pacific herring can be found throughout the relatively narrow coastal zone from northern Baja California on the North American coast, around the rim of the North Pacific Basin to Korea on the Asian coast (Outram and Humphreys 1974, Hart 1973). Within this range, herring abundance increases to the north (Figure 3.3), with the largest populations off Canada and Alaska

(Spratt 1981).

Open ocean surveys along the coast indicate that different age or size groups of Pacific herring tend to school separately (Hay 1985). Schooling by size may be due to size-related differences in swimming rates (Lambert 1987). Large schools may also segregate internally by size (Breder 1976).

Pacific herring aggregate in open ocean feeding grounds from late spring to early autumn. Some stocks (defined as a race using a discrete spawning area) of Pacific herring mingle on feeding grounds while others remain isolated (Carlson 1980, Barton and Wespestad

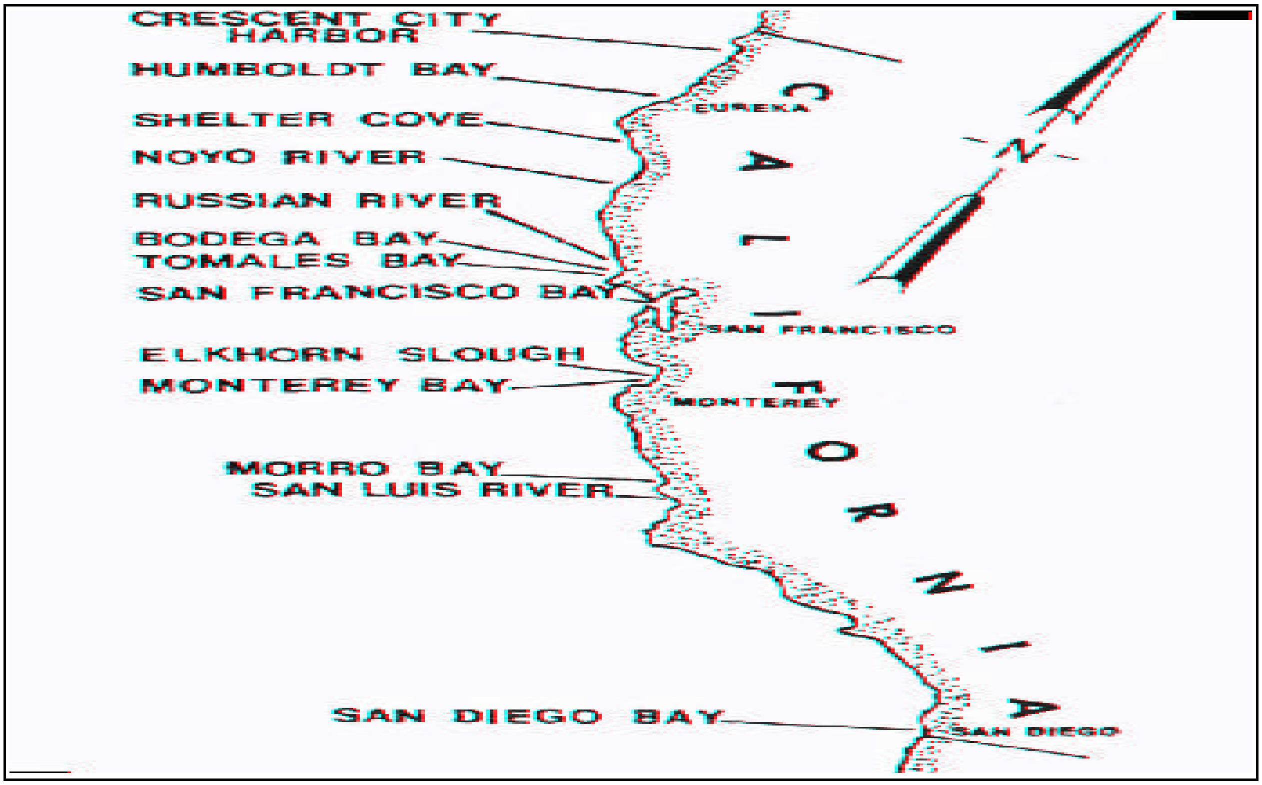
1980). Using parasites as biological tags, Moser and Hsieh (1992) suggest that Tomales Bay and San Francisco Bay herring are separate stocks that do not mingle in the open ocean [Sec 4.2.6.1].

A tagging study by Hourston (1982) of Canadian stocks of Pacific herring found that fish homed to specific spawning areas (Hourston 1982). The extent of homing varied between 66 and 96 percent and seemed to be related more to previous spawning experience than to where the fish themselves hatched. Harden-Jones (1968) obtained comparable results and identified a tendency for older fish to stray [Sec 4.2.6.1]. All, or nearly all, herring-like fish reduce their feeding and spawning range as the population declines (Murphy 1977)[Sec 4.2.6.1].

In California, herring have been found during the summer near Monterey and Morro Bays and offshore of the Farallon Islands (Miller and Schmidtke 1956). The herring found near Monterey Bay were not produced locally (Phillips et al. 1986) and may have originated from San Francisco Bay spawning grounds (Moser and Hsieh 1992, Moser 1983).

In early autumn, Pacific herring migrate inshore to holding areas and spawning grounds. Holding areas tend to be close to the spawning grounds (Ware and Tanasichuk 1989). Herring can arrive at least three months before spawning but arrival varies from year to year depending upon such factors as weather and food availability (Blaxter and Hunter 1982). Prokhorov (1968) found that maturation and migration to spawning grounds occurred earlier in warmer years.

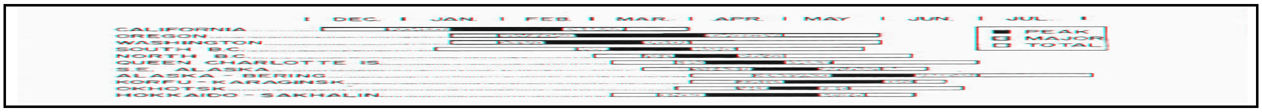
Herring are known to spawn at many locations along the California coast (Figure 3.4)(Spratt 1981). Historic spawning areas in California are: San Diego Bay, San Luis River, Morro Bay, Elkhorn Slough, San Francisco Bay, Tomales Bay, Bodega Bay, Russian River, Noyo River, Shelter Cove, Humboldt Bay, and Crescent City (Miller and Schmidtke 1956, Spratt 1981). Spawning areas south of San Francisco Bay are minor and may not support spawning



every year. Spawning areas from San Francisco Bay north to Crescent City (except for the Russian River and Shelter Cove areas) are considered to be regular spawning areas. Those spawning areas with established commercial herring roe fisheries are described in greater detail [Sec 3.3].

3.2.1.3 Spawning

Pacific herring and Atlantic herring are the only two marine fish in the herring family to laytheir eggs on the bottom (demersal eggs)(Blaxter and Hunter 1982). Pacific herring typically spawn in the intertidal or shallow subtidal areas of open ocean or protected bays and estuaries (Spratt 1981, Alderdice and Hourston 1985). However, due to their ability to adapt to a wide range of temperatures and salinities they may also spawn in the tidal portions of rivers and brackish lakes and lagoons (Alderdice and Hourston 1985). The system of site selection and



reproductive behavior is designed to maximize the potential for egg and larval survival. Many locations with these general characteristics are not used, indicating that spawning habitat may not be a limiting factor in determining population size.

The timing of spawning is believed to coincide with the peak in plankton production in order to insure an adequate food source for larval fish (Cushing 1975) [Sec 3.2.1.9]. In higher latitudes, where plankton production cycles are short, the timing of spawning of Pacific herring can be more precise. In lower latitudes, plankton production cycles are more variable, resulting in longer spawning seasons (Blaxter and Hunter 1982, Hay 1985, Haegele and Schweigert 1985)(Figure 3.5). Spawning in California typically begins in early November, peaks in January, and may extend through March (Rabin and Barnhart 1986, Spratt 1981, Reilly, Oda and Wendell 1989).

Within a spawning season, temperature and fish size play important roles in the exact timing of spawning, by affecting the timing of gonad maturation (Ware and Tanasichuk 1989). As a result, Pacific herring generally enter and use spawning grounds in a succession of spawning waves, rather than all fish spawning at a single time (Reilly and Moore 1983, Lambert 1987, Hay 1986, Barton and Wespestad 1980).

In San Francisco Bay, the number and size of spawning waves is related to the age structure of the spawning population, with older age-classes tending to spawn early in the season,

and younger age-classes spawning later in the season (Oda 1994). Pacific herring in California begin reaching sexual maturity at age two, and are fully recruited to the spawning population at age three (Spratt 1981, Reilly and Moore 1984). During years of poor recruitment, when two- and three-year-old fish appear in low numbers, spawning may only continue into February. When recruitment of two- and three-year-old fish is high, spawning may continue well through March. A broad age structure will tend to promote resilience or stability in a population by averaging out the effects of age on reproduction (Lambert 1987).

Little is known about which factors act as stimuli to initiate spawning for California herring, but salinity may play an important role (Barnhart 1988). When the right conditions exist, herring move into intertidal and shallow subtidal areas and spawn on any suitable substrate, such as vegetation, rocks, shell fragments, or other hard surfaces such as pier pilings.

The number of eggs laid per unit of body weight (fecundity) by Pacific herring is lower than many other fish species, but numbers of individual herring are high (Blaxter and Holliday 1963). However, the fecundity in Pacific herring is variable. For example, the fecundity of herring in California is higher than for herring in Canada and Alaska (Hay 1985, Tanasichuk and Ware 1987). The average fecundity of female herring in California is approximately 220 eggs per gram of body weight compared to 200 for herring in British Columbia (Hardwick 1973, Rabin and Barnhart 1977, Reilly and Moore 1986, Tanasichuk and Ware 1987).

A few sperm-releasing males can induce spawning behavior in a large number of fish (Stacy and Hourston 1982, Hay 1985). Rounsefell (1930) described Pacific herring spawning as coordinated sexual behavior. The substrate can be tested by spawners and sediment on the substrate may inhibit spawning (Stacy and Hourston 1982) [Sec 4.2.2]. Eggs are laid in varying numbers of layers. Spawn density varies from an egg or two per square meter of substrate to complete coverage in layers six to eight eggs thick (Spratt 1981).

Survival of the embryo (fertilized egg) is dependent on a number of variables. Egg density and water transport through the egg mass significantly influences embryo survival (Galkina 1971, Alderdice and Hourston 1985, Haegele and Schweigert 1985). Exposure to air can also contribute to losses through hypoxia, desiccation, and temperature differences (Jones 1972, Purcell, and Grover 1990). Jones (1972) found that the smaller eggs produced by smaller herring were less likely to survive air exposure than larger eggs. From this, Jones (1972) postulated that the reduction in average size of herring caused by harvest could result in lower survival of eggs exposed to air. Taylor (1971) and Jones (1972) examined the effect of egg density on survival. Taylor (1971) found hatching success to decrease with increased egg mass thickness, with optimal thickness at two to four egg layers for subtidal spawn. Jones (1972), who examined intertidal spawns, reported optimal survival from seven layers of eggs.

Other significant factors influencing egg survival include predation by birds, fish and invertebrates, cannibalism, storm loss, and siltation**.** Estimates of total predation vary significantly (Lough et al. 1985). Losses from predation and storms have been reported as low as 10 percent (Haegele et al. 1981) and as high as 90 percent (Hardwick 1973). Bird predation is considered to be a significant source of loss (Outram 1958, Spratt 1981, Bayer 1980, Barton and Wespestad 1980) [Sec 3.2.1.8]. However, at lower spawn densities, bird predation may not be a significant source of egg loss (Rabin and Barnhart 1986). Storms and wave action can also contribute significantly to egg loss on occasion (Hay and Miller 1982, Taylor 1964, Haegele and Schweigert 1985) as can siltation (Galkina 1971, Haegele and Schweigert 1985) [Sec 5.2].

The incubation period is temperature and egg size dependent. Warmer temperatures will lead to earlier hatches as will smaller egg size. Incubation time was 6-10 days in water temperatures of 8-10°C in Tomales Bay (Miller and Schmidtke 1956) and 10.5 days at an average water temperature of 10°C in San Francisco Bay (Eldridge and Kaill 1973).

3.2.1.4 Larval Stage

At hatching, Pacific herring are approximately 6 to 8 mm in length (Barnhart 1988). Immediately after hatching, the larvae have a yolksac and no swimming ability. Their distribution is clumped, controlled largely by tidal factors (Henri et al. 1985). The duration of the yolksac stage is dependent on the amount of yolk present and temperature (Fossum 1986). The time from exhaustion of yolk to the point where irreversible starvation occurs is also temperature dependent (McGurk 1984). With absorption of the yolksac and active swimming and foraging, larval distribution becomes patchy (McGurk 1987).

Larval starvation may be a critical factor in determining year-class strength (Hay 1983, Cushing 1975, Kiorboe et al. 1985). The period between exhaustion of yolk and irreversible starvation is, thus, a critical period in the herring life cycle (Anthony and Fogarty 1985, Blaxter and Holliday 1963, Hay 1983) [Sec 3.2.1.9].

Other factors that affect larval survival are competition, predation (Lasker and MacCall 1983), cannibalism (MacCall 1980), and larval drift (Parrish et al. 1981, Nelson et al. 1977). Variation in egg survival (Lo 1985), changes in fish fecundity (Picquelle and Hewitt 1983), and the effect of localized oceanographic events (storms and upwellings)(Lasker 1975, 1978) or widespread oceanographic events (unusual warming of the ocean - El Niño) also affect larval survival.

Larval herring develop swimming powers when they are 20 mm long (6 weeks old). With mobility, Atlantic herring avoid the surface during fast moving flood and ebb tides and use the surface waters during slack tides. This vertical migration promotes estuary residency (Henderson 1987). Metamorphosis from the slender, nearly transparent larval form to the green/silver adult form occurs at approximately 30 mm (10-12 weeks old).

3.2.1.5 Juvenile Stage

Upon completion of metamorphosis, juvenile Pacific herring are free swimming and form shoreline oriented schools. The schools enlarge and move out of the bays as summer progresses (Taylor 1964, Reilly and Moore 1983). Very little is known about the juvenile stage from the time they leave inshore waters in their first summer until they are recruited into the adult population at age two or three.

Data suggest that one- and two-year-old herring do not associate with adults offshore. Two-year-olds may be found in the same area as adults, but appear to maintain discrete schools (Taylor 1964).

3.2.1.6 Offshore Life History

Little information is available regarding the abundance, behavior, and ecological relationships of Pacific herring once they arrive in offshore feeding areas. Atlantic herring typically undergo vertical migrations to feed, rising toward the surface as light decreases and descending as light increases (Wales 1984). Vertical migration may help Atlantic herring find plankton near the surface in light intensities where they are less vulnerable to predation (Blaxter and Parrish 1965). The heaviest feeding periods, then, are dusk and dawn.

Herring schools in general occupy a small proportion of offshore feeding areas at any given time, but their presence can have a strong local affect on the community. They can reduce zooplankton populations through predation, and increase phytoplankton growth by introducing concentrations of nutrients found in their waste products (Blaxter and Hunter 1982).

Herring predation and availability as prey may have other effects in the offshore ecosystem. Predation by Atlantic herring on fish eggs has had area-specific impacts on fish populations (Daan et al. 1985). Under the right conditions, Pacific herring foraging in Puget Sound may cause salmon to switch prey to less suitable forms, potentially affecting growth and survival of salmon (Fresh 1983). Offshore populations of Pacific herring have declined in relation to increases in Pacific hake, *Merluccius productus*, populations (Day 1987). The paleosedimentary record of anaerobic basins (quantity of identifiable fish scales laid down through time) shows large fluctuations in offshore clupeoid biomass (Lasker 1985).

A number of physical features can have profound effects on the offshore community, and herring offshore life history. Changes in ocean currents, for example, affect many different organisms (phytoplankton, zooplankton, sockeye salmon)(McLain and Thomas 1983) [Sec 5.4]. The invasion of warm nutrient-depleted water (El Niño) affects the movement, distribution, growth and survival of a number of species (Spratt 1987, Lasker 1985).

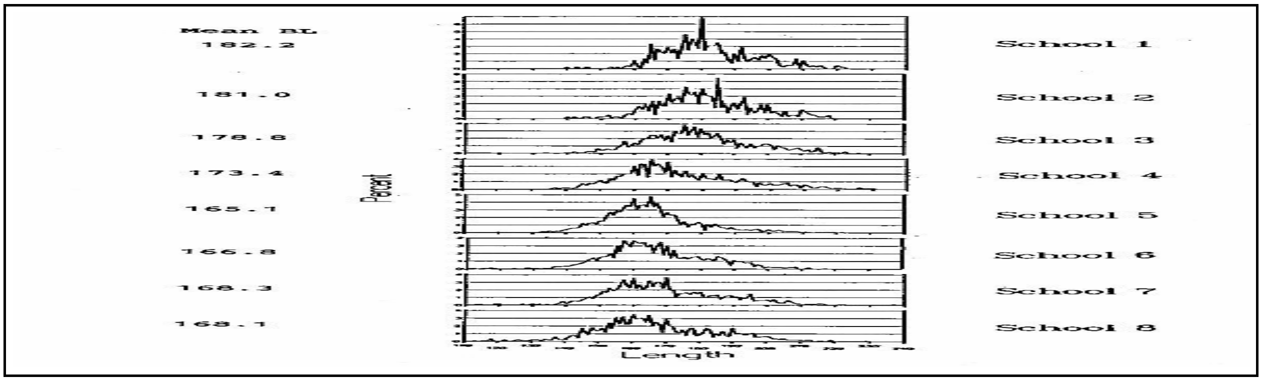
3.2.1.7 Age and Growth

A number of age determination methods have been developed to provide the population age structure information used in fisheries management (Chilton and Beamish 1982, Nielsen and Johnson 1983). Pacific herring scales and otoliths (ear bones) show zones of growth which are used to determine age (Rounsefell 1930, Spratt 1981, Chilton and Stocker 1987).

Pacific herring have been found to attain an age of 15 years (Barton 1978). They occur in California fisheries from age 2 through 11 (Spratt 1981, Reilly, Oda and Wendell 1989, Rabin and Barnhart 1986). The age composition of spawning populations is influenced by dominant year-classes and can vary considerably (Reilly, Oda and Wendell 1989).

Pacific herring in the San Francisco Bay spawning population range in size from approximately 110 to 240 mm in body length (BL). The average size of herring within the population on the spawning grounds changes in a consistent manner through the spawning season. Larger herring spawn earlier in the season. Successive waves of spawners have smaller average size as younger fish move onto the grounds (Figure 3.6)(Reilly, Oda and Wendell 1989, Spratt 1981).

A few 1-year-old herring have been found on the spawning grounds in a mature state. Typically 2-year olds are the youngest herring found in the San Francisco Bay spawning

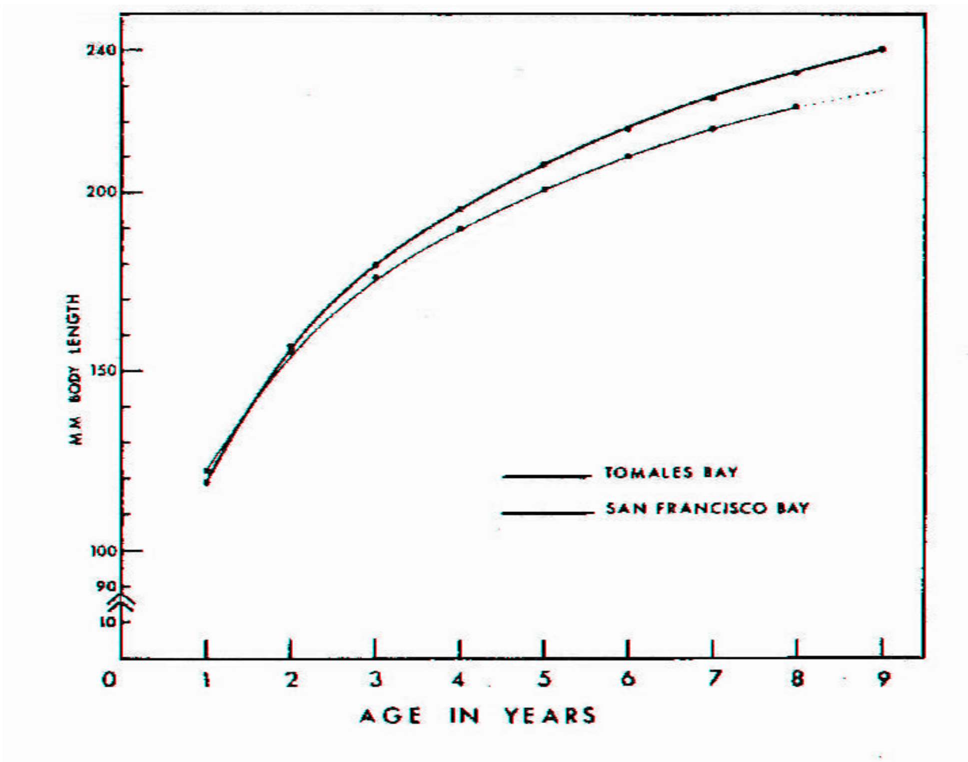


population (Reilly and Moore 1983, Oda and Wendell 1990). However, not all 2-year olds join the population as first time spawners (Reilly and Moore 1987, Spratt 1981). Three-year oldherring are considered fully recruited to the spawning population (Reilly and Moore 1984, Spratt 1981).

Growth of immature Atlantic and Pacific herring differs among areas and between year-classes (Anthony 1971, Gonyea and Trumble 1983, Haist and Stocker 1985, Iles 1967, Levings 1983, Reilly 1988). Variation in growth is generally attributed to environmental factors and the abundance of young herring. Environmental factors are the primary cause of differences in adult herring growth (Murphy 1977, Reilly and Moore 1984, Spratt 1987). Differences in age-specific size between Tomales and San Francisco Bay spawning populations have been consistent and suggest different stock origins (Figure 3.7)(Spratt 1981). The maximum size of Pacific herring increases with latitude throughout its range (Gonyea and Trumble 1983).

3.2.1.8 Natural Mortality

There are many causes of death (mortality) among the fish in a population; removals by humans (fishing), predation, and disease are examples. In practice, causes of death are divided into two categories: fishing and natural mortality (which includes everything else)(Ricker 1975). Massive mortality caused by epidemics has devastated some populations of Atlantic herring (Sissenwine et al. 1984). Toxic substances produced by algae used as a spawning substrate by the Baltic herring, *Clupea harengus membras*, have also been identified as a source of natural mortality (Aneer 1987). Adult Atlantic herring have on several occasions died during blooms of a toxic species of plankton (*Gonyaulax excavata*)(White 1980). Predation, however, is widely recognized as a more significant source of natural mortality.



Causes of natural mortality and mortality rates typically vary with the age of fish within a population (Gulland 1988). This is particularly true when all life stages are considered (egg, larvae, juvenile, and adult). The causes of mortality at the egg stage vary to a greater extent than they do in subsequent stages in the herring life cycle, and have been reviewed in a prior section [3.2.1.3]. However, predation is considered to be the primary cause of natural mortality in juvenile and adult herring populations (Ware and Tanasichuk 1988, Walters et al. 1986, Outram 1958, Lasker 1985, Day 1987, Daan et al. 1985, Bayer 1980).

3.2.1.8.1 Predation

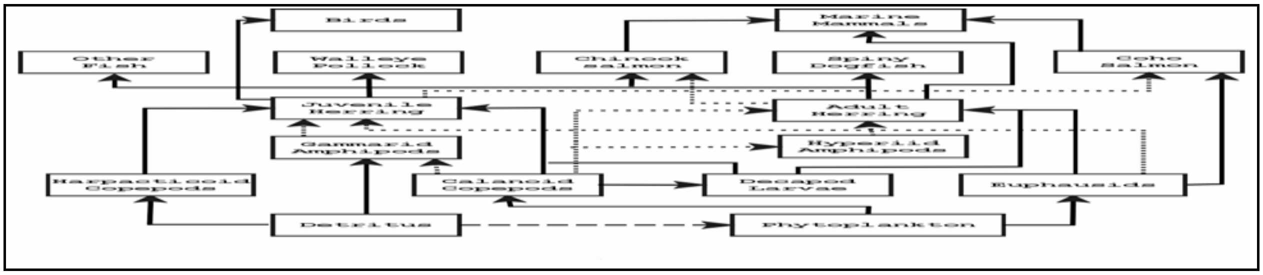
Predation during the egg stage of Pacific herring is recognized as a significant cause of natural mortality. At least 20 species of birds alone are known to feed upon Pacific herring eggs (Table 3.1)(Bayer 1980). In many cases, bird predation has been identified as the primary source

Table 3.1. Birds Observed Eating Pacific Herring Eggs.		
Black Brant	White-fronted Goose	Redhead
American Wigeon	Greater Scaup	Canvasback
Lesser Scaup	Common Goldeneye	Bufflehead
Harlequin Duck	Black Scoter	Oldsquaw
Surf Scoter	White-winged Scoter	Western Gull
American Coot	Glaucous-winged Gull	Mew Gull
Ring-billed Gull	Bonaparte's Gull	

of mortality (Outram 1958, Hardwick 1973, Bayer 1980, Haegele and Schweigert 1985). The species composition and abundance of the bird predator population is determined by migrations, immigrations to feeding areas, and competition (Bayer 1980, Norton et al. 1990). Glaucous-winged gulls appear to be dominant bird predators on eggs deposited within the intertidal zone in some areas (Norton et al. 1990). They also obtain herring eggs by piracy (stealing from other birds) as do some diving birds.

Non-avian predators on Pacific herring eggs include sturgeon, surfperch, smelt and crabs (Hardwick 1973). Pacific herring are also known to cannibalize herring eggs (Hay 1985). Spent (just spawned) Pacific herring were found on spawning grounds with their stomachs filled with herring eggs. Cannibalism has also been noted in the Atlantic herring (Blaxter and Holliday 1963).

Herring larvae are preyed upon primarily by invertebrates (animals without backbones)



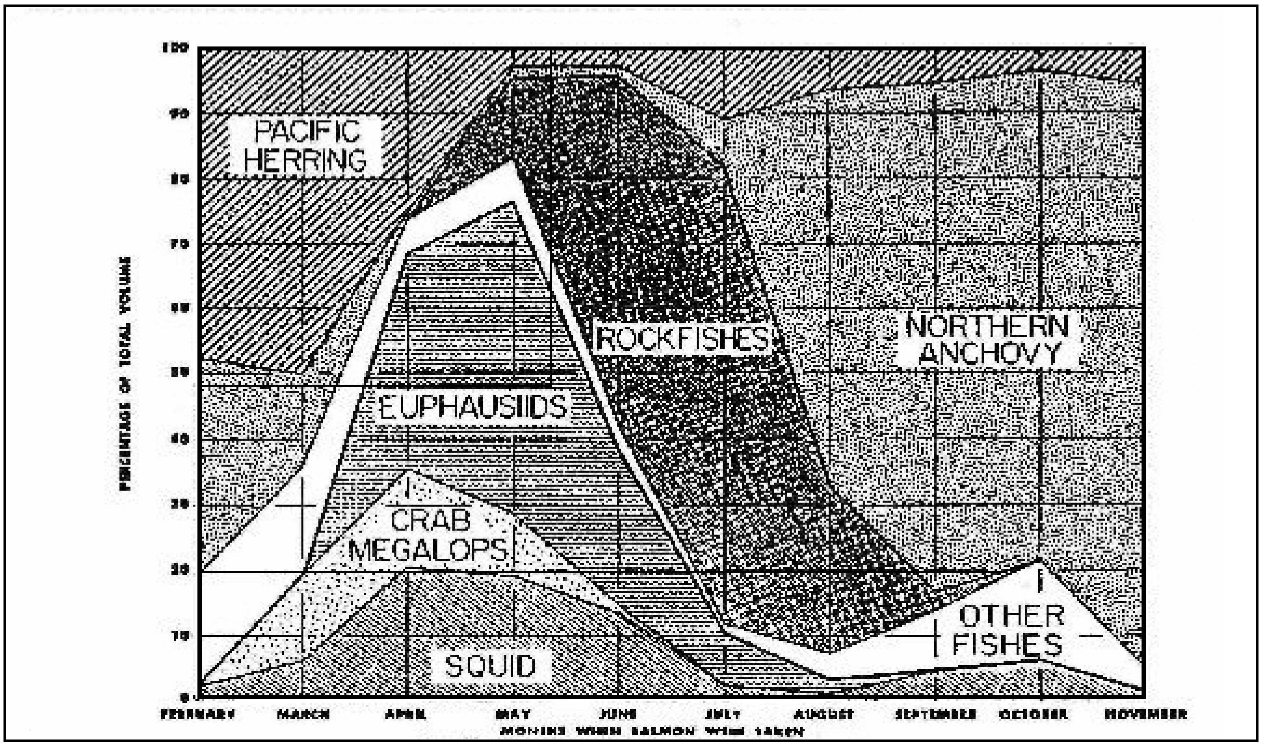
(Arai and Hay 1982, Blaxter and Holliday 1963, Hourston et al. 1981, Moller 1984, Purcell et al. 1987). Chief among the invertebrate predators are various species of jellyfish and comb jellies. *Sarsia tubulosa* and *Aequorea victoria* (jellyfish) have been identified as potentially significant predators on Pacific herring larvae (Arai and Hay 1982, Purcell et al. 1987). *A. victoria* is a significant predator for a short period after a hatch, consuming yolksac larvae (12 mm) with limited swimming ability. The ability of larvae to escape contact increases dramatically beyond that size. Small perch, young salmon, amphipod crustaceans and arrowworms (chaetognaths) have also been identified as predators on larval Pacific herring (Stevenson 1962).

Information on the importance of juvenile and adult Pacific herring as prey is limited. As consumers of zooplankton (secondary consumers), herring have an important role in transferring energy from lower feeding strata (phytoplankton and primary consumers) to upper strata when they, in turn, are consumed (Figure 3.8)(Fresh 1983). A number of piscivorous (fish-eating) fish, birds, and marine mammals have been identified as predators of Pacific herring juveniles and adults.

Predation by Pacific whiting may have a significant effect on herring biomass in offshore areas (Day 1987, Walters et al. 1986, Ware and McFarlane 1986, Ware and Tanasichuk 1988). A correlation has been noted between increasing whiting abundance and decreasing herring abundance in studies off British Columbia and northern Washington. Rexstad and Pikitch (1986) estimated that Pacific whiting consumed 120 tons per day of Pacific herring in the area between central Oregon and northern Washington. However, the seasonal migration pattern of whiting along the Pacific coast and its latitudinal stratification by size class complicates application of feeding study results to other areas (Rexstad and Pikitch 1986). Other potentially significant fish predators of herring include salmon (chinook and coho), sharks (particularly dogfish), sablefish striped bass, steelhead trout, Pacific cod, and walleye pollock. Other fish predators include lingcod, several species of rockfish (black, yelloweye, quillback and tiger rockfish), northern anchovy, pink salmon, cutthroat trout, buffalo sculpin, staghorn sculpin, and sand sole. Most of these fish predators can be categorized as opportunistic feeders, capitalizing on accessible prey (Rosenthal et al. 1988, Emmett et al. 1986).

Fresh (1983) reported herring as a major diet item of chinook salmon in the Puget Sound area, particularly in the winter and spring. The typical length of herring from chinook stomachs was 110 mm, indicating they were juveniles less than 2 years old. Chinook salmon off the San Francisco area, on the other hand, tended to utilize larger herring (Merkel 1957). A marked seasonal change in the composition of the food used was related, to a certain extent, to shifts in the site of capture and prey availability (Figure 3.9). When Pacific herring were identified as the main food item for chinook salmon in Merkel's (1957) study, the salmon were taken in offshore herring holding areas near San Francisco Bay.

Juvenile and adult Pacific herring are also preyed upon by marine birds. Seabirds are important members of upper trophic levels (Furness and Ainley 1984). The extent of predation by seabirds on Pacific herring is relatively unknown. Ainley and Boekelheide (1990) found that of eight seabird species in the Farallon Island area capable of reaching depths of at least 50 m,



none included Pacific herring in their diet during the summertime breeding season. Availability may be limited in offshore areas by changes in herring depth distribution associated with daily vertical migrations; however, several central California seabirds are known to forage regularly to 100 m (Ainley and Boekelheide 1990).

Herring may be more vulnerable to seabird predation in the shallow water embayments typical of most spawning grounds. Flocks of Brandt's and double-crested cormorants, brown pelicans, western grebes, gulls, and loons are often observed diving on adult herring schools during spawning season within Tomales Bay and San Francisco Bay. Terns are likely consumers of herring young-of-the-year in the summer.

Pacific herring are consumed by a number of marine mammals including harbor seals, northern fur seals, California sea lions, Steller sea lions, harbor porpoises, Dall's porpoises, Pacific white-sided dolphins (Jones 1981) and whales (Hart 1973). The extent that California herring stocks are used by these marine mammals has not been well documented. Pacific herring are an intermediate host for several parasites with definitive hosts among marine mammals (cetacean, pinnipeds)(M. Moser, UCSC, pers. comm.). This fact and the relative position of herring in the trophic ecology of the region suggest their use is prevalent. Since California sea lions specialize on schooling, open water fishes, they may be one of the most significant of the mammalian predators of herring in California.

3.2.1.9 Food Habits

Early post-yolksac Pacific herring feed on a variety of micro-plankton (diatoms, protozoans, bivalve veligers, and copepod eggs, nauplii, and copepodites) (Purcell and Grover 1990). Larval copepods (shrimp-like crustaceans) predominated in the environment and in the stomach contents of the larval herring at the time of Purcell and Grover's study. Larval Atlantic herring growth rates were shown to increase with increased concentrations of copepod larvae (Kiorboe and Munk 1986) and the food size selected increased with larval size (Blaxter and Holliday 1963, Jones and Hall 1974).

Herring continue to feed on plankton throughout their life cycle, relying heavily on visual cues in feeding (Blaxter and Holliday 1963). Adults will switch feeding forms (filter or particulate feeding) based on food concentration and size to maximize number of prey (Boehlert and Yoklavich 1984, Gibson and Ezzi 1985, Blaxter 1985).

Feeding tends to occur at dawn and dusk (Fresh 1983, Blaxter and Parrish 1965). Both herring and their potential prey undergo vertical migrations. This behavior may maximize foraging opportunities during relatively restricted foraging times by helping to reduce search effort.

Foraging can have strong local effects on zooplankton community structure (Blaxter and Hunter 1982). Young Atlantic herring, for example, may have affected plaice recruitment by feeding on their eggs. However, their impact was felt to be area specific and related to availability (Daan et al. 1985). Prey items selected by Pacific herring change with their growth and geographic distribution.

Juvenile Pacific herring in shallow subtidal areas fed primarily on zooplankton (copepods and crab larvae)(Fresh 1983). All of the prey utilized eelgrass beds as habitat. Herring diet changed as a function of fish size, time of year, and habitat, all of which influenced prey availability. Euphausiids (shrimp-like crustaceans) became the primary food item when herring reached adult size and moved into offshore pelagic habitats.

3.2.1.10 Competition

Herring obviously compete with a number of organisms for food during their life cycle. Although not extensively studied, some data are available. Herring, for example, compete with juvenile and subadult coho salmon for food in the shallow sublittoral habitat (Fresh 1983) or for euphausiids in the offshore pelagic habitat (Fresh et al. 1981). Herring larvae compete with some of the soft-bodied zooplankton (medusae) for microplankton (Purcell and Grover 1990).

3.2.1.11 Habitat

The general distribution of fish, including herring, is influenced by water movement and properties of water, principally currents, upwelling, temperature, and salinity. Pacific herring complete their entire life cycle within one portion of the North Pacific water-mass known as the coastal zone. The coastal zone is characterized by waters of reduced salinity (due to freshwater run-off from land) and low temperature (0-13°C). It includes sheltered bays used for spawning, and localized, nutrient-rich, plankton-producing areas of higher salinity associated with upwelling (Outram and Humphreys 1974).

Certain temperatures and salinities have been identified as optimal for Pacific herring spawning (3-9°C and 8-22 ppt) and for egg and larval survival (5-9°C and 13-19 ppt)(Alderdice and Velsen 1971, Prokhorov 1968). Adults have a much wider range of tolerance (Brawm 1960). California is near the southern limit of the North American distribution of Pacific herring. As a consequence, temperature and salinities are not typically within the optimal range; however, they do fall within the tolerance range (Alderdice and Velsen 1971).

Other characteristics of spawning habitat have also been identified as important factors in herring survival. Adequate spawning substrate, free of sediment and filamentous algae, is one such requirement (Graham and Townsend 1985, Aneer 1987, Blaxter and Holliday 1963). Pacific herring are capable of using a wide variety of substrates for spawning (Spratt 1981). A number of factors influence the distribution and availability of vegetation including agricultural herbicides in runoff, erosion input of fine grain sediments and nutrient enrichment (Kemp et al. 1983). Eelgrass distribution has been limited by its tolerance to exposure, turbidity, and by waterfowl grazing (Harrison 1982). The reduced rate of growth in winter could slow eelgrass recovery from grazing (Aioi et al. 1981).

Water transport through the spawning grounds has a number of effects. It influences egg survival (Alderdice and Hourston 1985, Galkina 1971), larval and juvenile food production (Stocker et al. 1985, Cloern et al. 1983), and larval and juvenile distribution (Blaxter and Hunter

1982, Corten, 1985, Graham and Townsend 1985). Currents can limit competition for food or remove larvae from favorable nursery areas. They can also influence the abundance of competing or predatory forms. Weather conditions, particularly storm waves, can lead to significant mortality of eggs.

Water temperature determines the rate of development. It also influences larval survival and year class strength (Anthony and Fogarty 1985, McGurk 1984, Sissenwine et al. 1984). It influences the rate of yolksac absorption (Fossum 1986) that, in turn, can influence survival through first feeding. In offshore areas, temperature can influence growth rates and the onset and rate of sexual maturation (Barton and Wespestad 1980, Lambert 1987).

3.2.2 Population Status

The Pacific herring roe fishery in California has been intensively regulated since its inception in 1973. Estimates of the size of the spawning population have provided the major source of information used to modify the regulations, as necessary, to insure long-term productivity of the herring resource.

Wide fluctuations in population abundance, due primarily to variable recruitment (fluctuations in the size of the youngest age class in the fishery), are a normal feature of short-lived pelagic fish populations (Appendix 3). As a result, frequent short-term assessments are necessary to update information databases used in developing fishery regulations. The information necessary to determine the annual status of California's Pacific herring population include: 1) current stock size, 2) current age structure, 3) fishery landings history, and 4) potential recruitment level.

The principle assessment methods used for monitoring the population abundance of herring are the egg deposition or spawn escapement surveys and hydroacoustic surveys (Spratt

1981, Rabin and Barnhart 1986, Reilly and Moore 1983, Miller and Schmidtke 1956, and Hardwick 1973) [Sec 3.2.2.1]. A variety of other indirect assessment methods have been used by resource managers worldwide to assess herring abundance. These methods include cohort analysis (analysis of age structured fisheries data), ecosystem modeling, and forecasting year class strength (Pope 1972, Ricker 1975, and Stocker et al. 1985).

The usefulness of these stock assessment methods is dependent on how the data are collected (data quality). Data must be sensitive (precise and accurate) enough to detect the extent of short-term changes in stock structure and abundance (Hourston 1980, Doubleday 1985). The use of several independent assessment procedures can reduce the strong dependency on precision and accuracy required of a single procedure (Schweigert and Stocker 1988).

Commercial catch samples and fishery independent midwater trawl samples have been used to assess population age structure (Spratt 1981, and Reilly, Oda, and Wendell 1989). A forecasting procedure is being used to predict future recruitment (projecting recruitment levels prior to their occurrence)(Oda and Wendell 1990). A description of each of these procedures and summaries of the data they have provided follows.

3.2.2.1 Biological Procedures

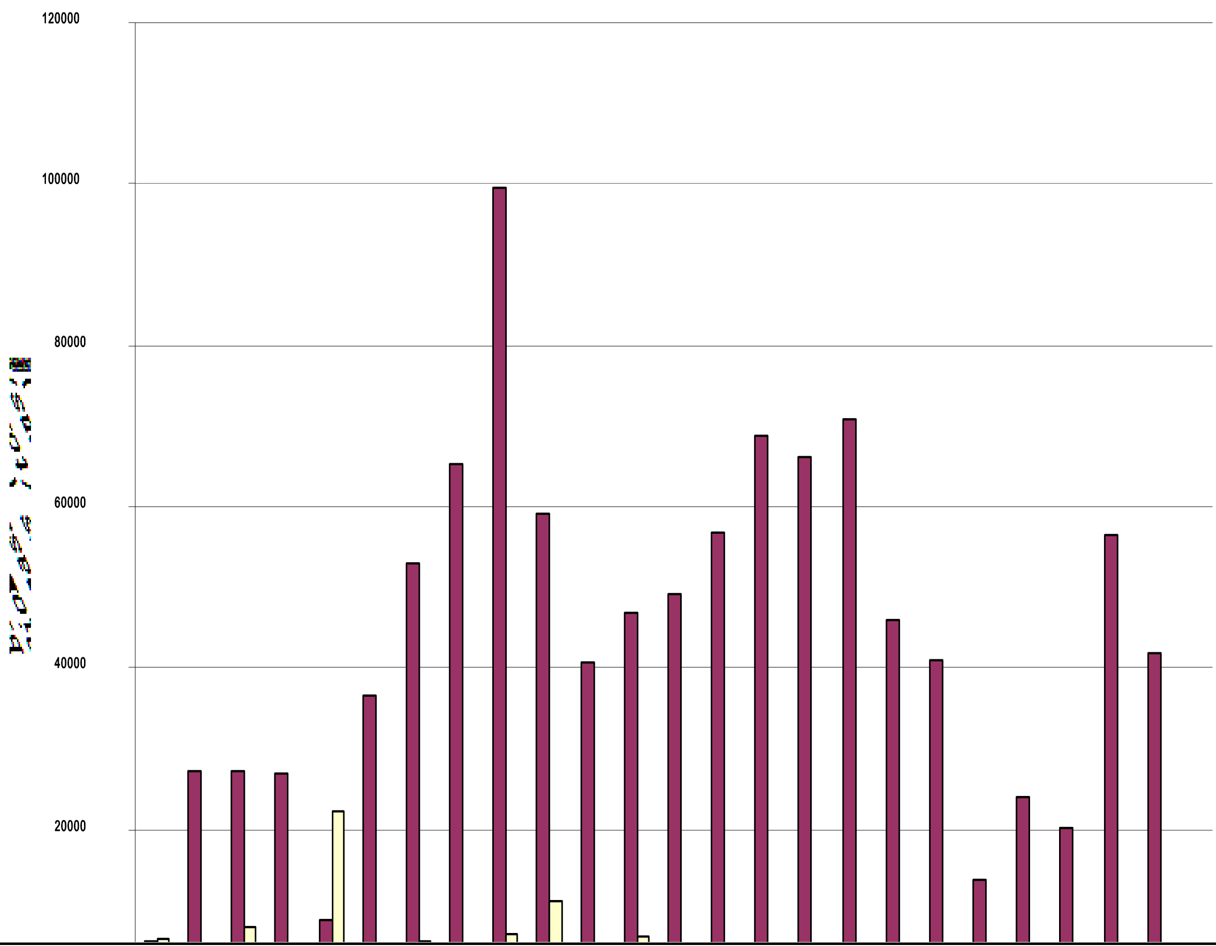
3.2.2.1.1 Spawn Escapement Surveys

Spawn escapement surveys have been used to assess Pacific herring abundance (biomass) in California at Elkhorn Slough, San Francisco Bay, Tomales Bay, and Humboldt Bay (Phillips et al. 1986, Spratt 1981 and 1991, Miller and Schmidtke 1956, Hardwick 1973, and Rabin and Barnhart 1986). The frequency of these surveys and exact methodology have varied. Tomales Bay and San Francisco Bay (sites of the largest spawning aggregations and fisheries) are surveyed annually and thus have a long time series of data with little change in data collection procedures (Spratt 1990). The remaining areas have been surveyed infrequently.

Spawn escapement surveys estimate biomass by measuring the area and density of eggs. Estimates of total egg production are converted to tons of fish that have spawned (biomass) by dividing by the average number of eggs laid per weight of female herring (fecundity). The procedure used by the Department is described in greater detail in Spratt (1981). Procedures used by other researchers conducting spawn escapement surveys in California have varied slightly.

Biomass estimates for the San Francisco Bay spawning stock, based on Department spawn escapement surveys, have been cyclical through time (Figure 3.10). The increase during the 1978-79 spawning season was due to expansion of the survey area to include assessment of subtidal spawning. Other Department assessment data (hydroacoustic and cohort analysis) follows the same general cyclical pattern. Since 1979, San Francisco Bay herring biomass estimates have peaked three times (Figure 3.10).

Figure 3.10. San Francisco & Tomales Bay spawning stock biomass estimates based on CDFG spawn escapement surveys. (not conducted in 1978 & 1985 in Tomales Bay).



Biomass estimates for Tomales Bay have varied greatly. The 1992-93 season saw the Tomales Bay herring biomass estimate rebound to a figure that approached the average spawning biomass for the last 23 years. In the following season the biomass dropped but rebounded in the 1994-95 season to the second highest biomass estimate for the preceding eight years. In the 1995-96 season the spawning biomass of 2,085 tons fell again below the 23-year average but was still just 10% lower than the 10-year average of 2,313 tons. Biomass estimates have continued to decline in the 1996-97 and 1997-98 seasons with estimates of 1,469 tons and 586 tons, respectively. Heavy rainfall most likely inhibited spawning in both seasons in addition to the compounding El Niño effects in 1997-98 on herring abundance, nutrition, and gonadal development, further depressing the spawning biomass estimate in Tomales Bay. Although no clear trend is evident with spawning biomass since the reopening of the Tomales Bay herring fishery in the 1992-93 season, there have been two El Niños and recently two extremely wet years in a row as the biomass has declined. Commercial catch rates have not been excessive since the fishery reopened and while the fishery was likely negatively impacted by the extended drought in the late 1980's, the latest shift in weather patterns to extremely wet winters is also quite likely to have negatively impacted spawning biomass estimates for the Tomales Bay herring population.. No other stock abundance assessment data are available for Tomales Bay.

3.2.2.1.2 Hydroacoustic Surveys

Hydroacoustic surveys determine the size and density of fish schools using sound transmission. Hydroacoustic surveys of Pacific herring spawning stocks have been conducted by the Department almost exclusively in San Francisco Bay. Initial development of procedures began in the early 1980's. The first estimate of spawning stock biomass was made during the 1982-83 spawning season (Reilly and Moore 1983). Methods used to collect and analyze hydroacoustic data have changed considerably through time.

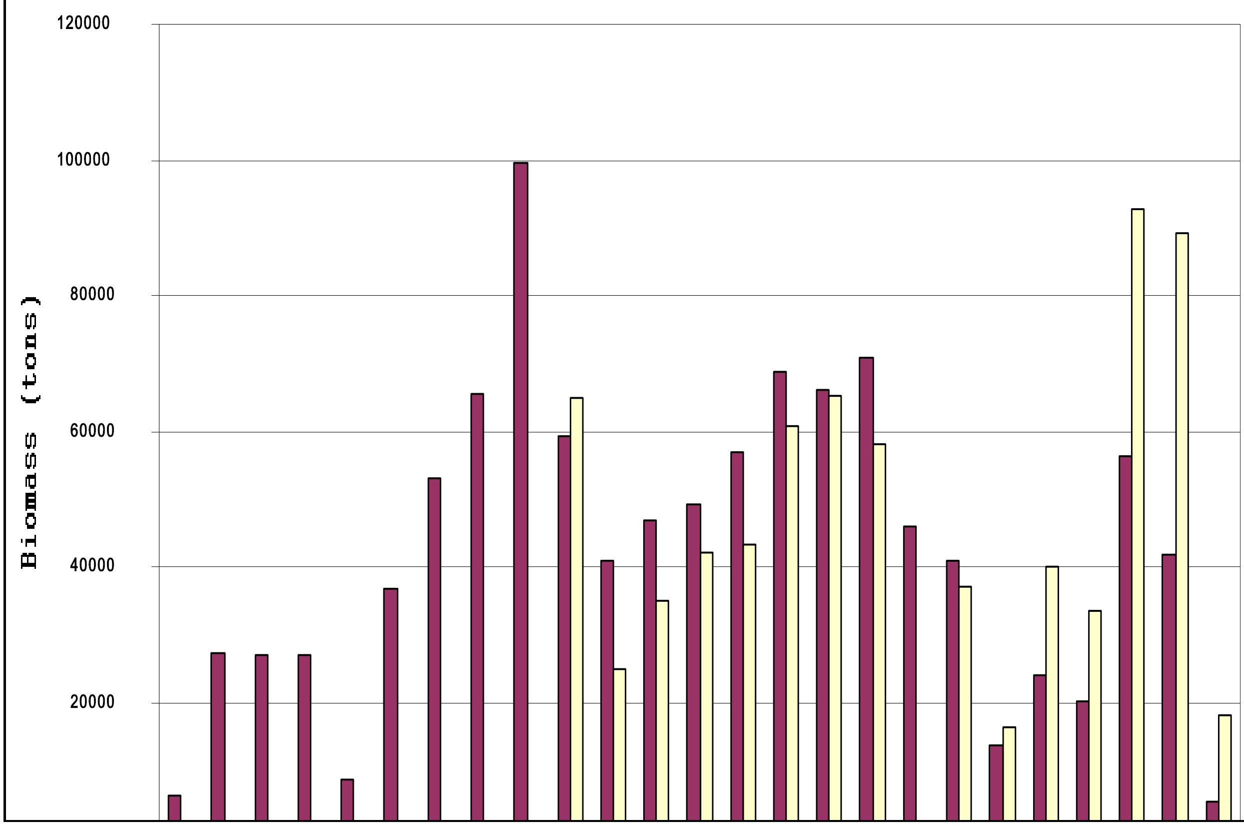
Early and present-day work is conducted with a scientific-grade echosounder (Raytheon model DE-719B) using the visual integration method. Echosounder plots of school density and area are obtained from diagonal transects across the school. Densities are determined for each transect based on comparisons to standards (visual integration). Standards were developed by chartering a purse seine vessel to capture and determine the actual weight of herring after obtaining an echosounder trace. The purse seine was assumed to capture a representative sample of herring at the density recorded by the echosounder. Initial translations of echosounder traces into biomass relied on mapping areas with equal density. The latest method averages densities along a track and applies that average to the area represented by the diagonal track.

An echo integration method was initiated in the 1986-87 spawning season to estimate spawning biomass of some schools and was utilized through the 1989-90 season. Basic data collection methods remained unchanged, other than using a refined echosounder (Biosonics model 105) and a transducer with a narrower beam width. Data analysis was initiated by processing tapes of stored data through an echo integrator. The integrator provided herring densities by depth strata. These were subsequently converted to biomass through multiplication by representative surface areas. Reduced staffing and technical difficulties with this equipment resulted in the discontinuation of the echo integration method.

The largest estimate obtained from either of the hydroacoustic methods was used when school biomass estimates were cumulated for a peak seasonal spawning biomass estimate. Biomass estimates of the spawning stock in San Francisco Bay from hydroacoustic surveys have generally followed a pattern similar to that shown by spawn escapement surveys (Figure 3.11).

<u>3.2.2.1.3. Spawn Survey Biomass Surveys Combined Hydroacoustic and</u>

Figure 3.11. San Francisco spawning stock biomass estimates based on spawn escapement & hydroacoustic surveys.
(1994 Partial Hydroacoustic estimate due to mechanical diffficulties).



Prior to the 1989-90 season, the hydroacoustic survey method was consideredexperimental and still under evaluation, and thus was not used for quota establishment. Beginning with the 1989-90 season, the San Francisco Bay herring population estimates from spawning ground and hydroacoustic surveys have been merged to generate a single "best" annual biomass estimate to use as a basis for calculation of herring catch quotas. Results from the two techniques are treated independently during the season, but following the season, results are reviewed on a school-by-school basis to obtain the most accurate biomass estimate of each spawning school.

Each survey method has its strengths and weaknesses, thus a merged biomass procedure attempts to minimize survey deficiencies. If both survey methods yield acceptable results for a given spawning event, then the biomass estimates are averaged. If the project staff encounters problems with one method (e.g. foul weather, equipment failure, or inability to gather adequate samples), then results from the other method are employed.

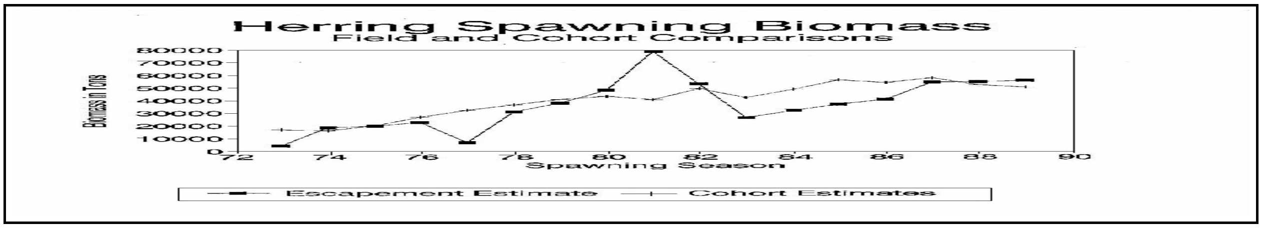
3.2.2.1.4 Age Composition Analysis

Information on historic stock sizes can be obtained from an analysis of the age of the fish taken in the commercial fishery (cohort analysis)(Pope 1972). Data for the analysis come from landing records which provide seasonal landings by gear type. Dockside sampling by the Department provides data on the size and age structure of the catch by gear type.

In a cohort analysis, the earlier estimates in a time series are more accurate reflections of stock abundance than are more recent estimates (Pope 1972). One great advantage of this type of analysis is that it can be used to verify other indices (fishery-independent stock abundance estimates).

A cohort analysis was completed by the Department for the San Francisco Bay stock, using the catch information described above from the roe fishery covering the period from the 1973-74 to the 1989-90 spawning seasons. Estimates from cohort analysis and spawn escapement surveys were compared using only the abundance of herring older than 2 years. The proportion of two-year-old herring in the population that join the spawning stock is large but variable. By eliminating all fish younger than three years from the comparison, the differences in the portion of two-year-olds represented by the two biomass estimates is controlled. Without correction, cohort analysis estimates all two-year-old herring and spawn escapement estimates an unknown proportion of that age group.

With few exceptions, the annual estimates from the two methods are very similar (Figure 3.12). Both suggest an increase in spawning biomass through the period analyzed (1973-74 to 1989-90). In two instances the estimate from cohort analysis was notably different. In the first instance (1977-78), a change in Department personnel may have lead to an underestimate based



on spawn escapement surveys. In the second, unaccounted for changes in natural mortality rates associated with the 1982-84 El Niño event may have lead to underestimates of biomass based on cohort analysis just prior to the event (1981-82) and slight overestimates immediately following the event.

<u>3.2.2.1.5 Forecasting</u>

Spawning biomass estimates are used as a basis for setting fishery quotas. Current management strategy is to base the quota on biomass estimates from the preceding season. This practice generally works well. However, significant fluctuations in biomass attributable to differences in recruitment have resulted in quotas being set too high and too low. The possibility of forecasting recruitment levels is being evaluated. An index of recruitment to the fishery has been developed based on the abundance of young-of-the-year herring in midwater trawl samples. If validated, the index could improve the method for setting quotas based on anticipated recruitment levels. The index accurately predicted poor recruitment of the 1990 year-class (Oda and Wendell 1990).

<u>3.2.2.2 Status of Stocks</u>

The status of Pacific herring stocks in California are evaluated by assessing abundance and age composition trends. Both types of information provide insight into a stock's resiliency to fishing mortality. Age composition information allows an assessment of survival at successive ages and provides a measure of the effects of fishing effort. This information is available to evaluate the status of San Francisco Bay and Tomales Bay stocks, which support the two largest roe fisheries, and partially available or completely absent for Humboldt Bay and Crescent City stocks.

3.2.2.2.1 San Francisco Bay Spawning Stock

San Francisco Bay supports the largest spawning stock of Pacific herring in California. All sources of information on stock abundance (spawn escapement, hydroacoustic surveys, and cohort analysis) show a fluctuating pattern of abundance over time (Figures 3.11 and 3.12). Several successive years of stronger than average year-classes from 1984 through 1988 allowed the spawning stock to build during those years (Table 3.2). This period was followed by two years of poor recruitment from the extremely weak 1989 and 1990 year-classes, resulting in a decline in spawning biomass which began with the 1990-91 season. A third consecutive year of poor recruitment from the 1991 year-class (as two-year-olds) resulted in the lowest spawning

Table 3.2. Estimated numbers of 2-, 3-, and 4-year-old Pacific Herring (X1000) by year-class in the San Francisco Bay spawning population. Numbers based on biomass estimates from: 1) spawn escapement surveys for 1981 to 1987 year-classes; 2) a combination of spawn escapement surveys for 1988 to 1994 year-classes

Table 3.2. Estimated numbers of 2-, 3-, and 4-year-old Pacific Herring (X1000) by year-class in the San Francisco Bay spawning population. Numbers based on biomass estimates from: 1) spawn escapement surveys for 1981 to 1987 year-classes; 2) a combination of spawn escapement surveys for 1988 to 1994 year-classes

Year Class	Age 2	Age 3	Age 4
1982	332,669	190,988	126,535
1983	185,742	160,613	134,528
1984	162,422	194,365	136,604
1985	168,962	292,508	139,248
1986	233,193	222,058	136,248
1987	146,525	237,377	[1]
1988	294,631	[1]	208,265
1989	[1]	126,616	79,045
1990	14,073	50,398	162,584
1991	48,925	136,333	94,833
1992	19,428	236,783	282,069
1993	39,363	359,357	183,370
1994	483,164	359,459	59,650[2]
1995	290,497	115,241[2]	
1996	24,178[2]		

[1] not available - incomplete 1990-91 field season.
[2] estimates are preliminary and subject to revision.

biomass estimate recorded during the 1992-93 season.

In San Francisco Bay, the appearance of two-year-olds usually provides a reasonable indication of year-class strength, although full recruitment to the spawning population does not occur until age three. The poor showing of the 1991 year class at age two was followed by an improved appearance at age three, and accounted for most of the increase in biomass for the 1993-94 season. Biomass remained essentially the same during 1994-95, with good numbers of two, three, and four-year-old herring. The very strong 1994 year class, in combination with the 1993 and 1992 year classes, accounted for the leap in spawning biomass to 99,000 tons during the 1995-96 season. These year classes in addition to a strong 1995 year class sustained spawning biomass at 89,570 tons during 1996-97.

Severe El Niño conditions during 1997-98 heavily impacted spawning biomass for San Francisco Bay. The 1997-98 spawning biomass estimate for San Francisco Bay was 20,000 tons, only 20% of the previous season's estimate of 89,570 tons. Given the very large spawning biomass estimates for 1996-97 (89,570 tons) and 1995-96 (99,000 tons), and the strength of the 1995, 1994, 1993, and 1992 year-classes, many fewer fish than expected returned to spawn during 1997-98. Whether El Niño conditions caused increased mortality for herring or simply prevented herring from reaching reproductive condition remains to be seen. Many of the fish that returned to spawn during the 1997-98 season were under-weight with under-developed gonads. Schools took an unusually long time to ripen and spawn.

3.2.2.2.2 Tomales Bay Spawning Stock

The information base available to evaluate the status of the Tomales Bay spawning stock is not as complete as that available for San Francisco Bay. Spawn escapement surveys indicate a high degree of variability in spawning biomass through time. The estimates of stock biomass for the 1988-89 season through the 1991-92 season are among the lowest since surveys began in 1973 (Spratt and Moore 1992). However, a trend of increasing biomass did continue from the 1989-90 spawning season estimate of 345 tons to the 1992-93 spawning season estimate of 4,079 tons, indicating the stock was in recovery. While the anticipated post El Niño decline did occur in the 1993-94 season, during the 1994-95 season the spawning biomass estimate rebounded to 3,979 tons, the second highest since the 1986-87 season. The 1995-96 biomass estimate of 2,085 tons fell again below the 23-year average but was still just 10% lower than the 10-year average of 2,313 tons. However, the 1996-97 biomass estimate of 1,469 tons is the lowest biomass estimate since the fishery reopened in the 1992-93 season. Heavy rains reduced bay salinities and most likely inhibited spawning and may have kept some herring from entering the bay since schools were small and commercial catches were light. It may be necessary to wait several more seasons to ascertain what the post-recovery average biomass will be.

The dominant age groups commonly caught in commercial gill nets and variable mesh research nets are 4- through 6-year-old herring. Fish caught with the variable mesh research gill net are more representative of the population structure and samples taken with these nets in recent years showed all age groups present in proportions suggesting good recruitment. The mean length of commercial gillnet-caught herring from small catches given to Department biologists by fishermen (there was never enough herring caught to make a landing) increased this season and was slightly larger than the 5-yr. average. The relatively strong 1992 year class of 6-yr-olds dominated the commercial catch samples and was responsible for the slight increase in mean length. Due to the poor condition of the herring this season, only the larger 5-year and older herring were caught in commercial gillnets. Tomales Bay research gill net catch was too small to be of value in the 1997-98 season.

Age composition of the commercial gill net catch does not show large changes in catch-at-age through time (Table 3.3)(Spratt and Moore 1992). However, the commercial gill net gear is selective for older ages and does not provide any indication of the abundance of younger ages in the stock. Although data do exist to indicate that San Francisco Bay and Tomales Bay stocks are indeed separate (Moser and Hsieh 1992), wandering from the San Francisco stock (migration into Tomales Bay) could be maintaining the apparent stability in age structure of the catch. However, without signs of significant change in age structure, and in light of significant differences in some consecutive biomass estimates that are not attributable to recruitment, migration of fish from Tomales Bay seems to be the most likely cause of the current low biomass level (Spratt 1990). The current status of the Tomales Bay stock is considered to be fair;

however, no clear trend is evident with recent spawning biomass estimates.

3.2.2.2.3 Other California Spawning Stocks

Very little information is available to evaluate the status of other spawning stocks in California. Spawn escapement surveys conducted during the 1974-75 and 1975-76 seasons in Humboldt Bay established the basis for the 60 ton Humboldt Bay quota (Rabin and Barnhart 1986). Spawn escapement surveys conducted in the 1990-91 season estimated a Humboldt Bay herring biomass of 400 tons, confirming the current quota is in the proper range (Spratt 1991). The Crescent City area also supports a small-scale fishery; however, beyond the aforementioned surveys, the status of the Crescent City stock and stocks not supporting fisheries is unknown.

Table 3.3. Age Composition of the Tomales Bay/Bodega Bay Gill Net Catch.

	Age (Percent by Number)							Mean	Size
Season	3	4	5	6	7	8	9	Length	Range
77-78[1/]	-	1	11	41	29	17	1	217	194-248
78-79				no samples					
79-80	-	14	41	27	4	14	1	214	196-236
80-81	3	10	30	33	15	7	2	208	172-234
81-82	2	8	21	28	25	13	3	211	176-236
82-83	-	4	24	34	24	11	3	208	184-236
83-84	-	13	36	35	11	2	3	199	174-242
84-85	7	13	27	33	15	4	1	202	164-232

85-86	14	25	27	18	10	5	1	198	166-226
86-87	4	20	38	27	6	3	2	197	174-236
87-88	<1	11	31	34	18	4	<2	201	170-234
88-89	4	22	33	28	9	3	1	197	170-236
89-90	2	9	18	37	26	8	-	204	172-222
90-91	4	21	32	26	12	4	1	197	174-232
91-92	10	26	37	21	6	-	-	194	168-214
92-93[2/]	1	15	47	30	7	-	-	196	166-226
93-94[2/]	<1	14	40	36	8	2	-	197	170-234
94-95[2/]	6	18	32	19	21	4	-	196	164-230
95-96[2/]	4	50	34	8	2	2	-	189	164-223
96-97[2/3/]									
97-98[2/]	-	-	18	68	14	-	-	196	194-212

[1/] Tomales Bay has been a gill net only fishery since 1977.
[2/] Outer Bodega Bay closed to herring fishing.
[3/] No data currently available for this season.

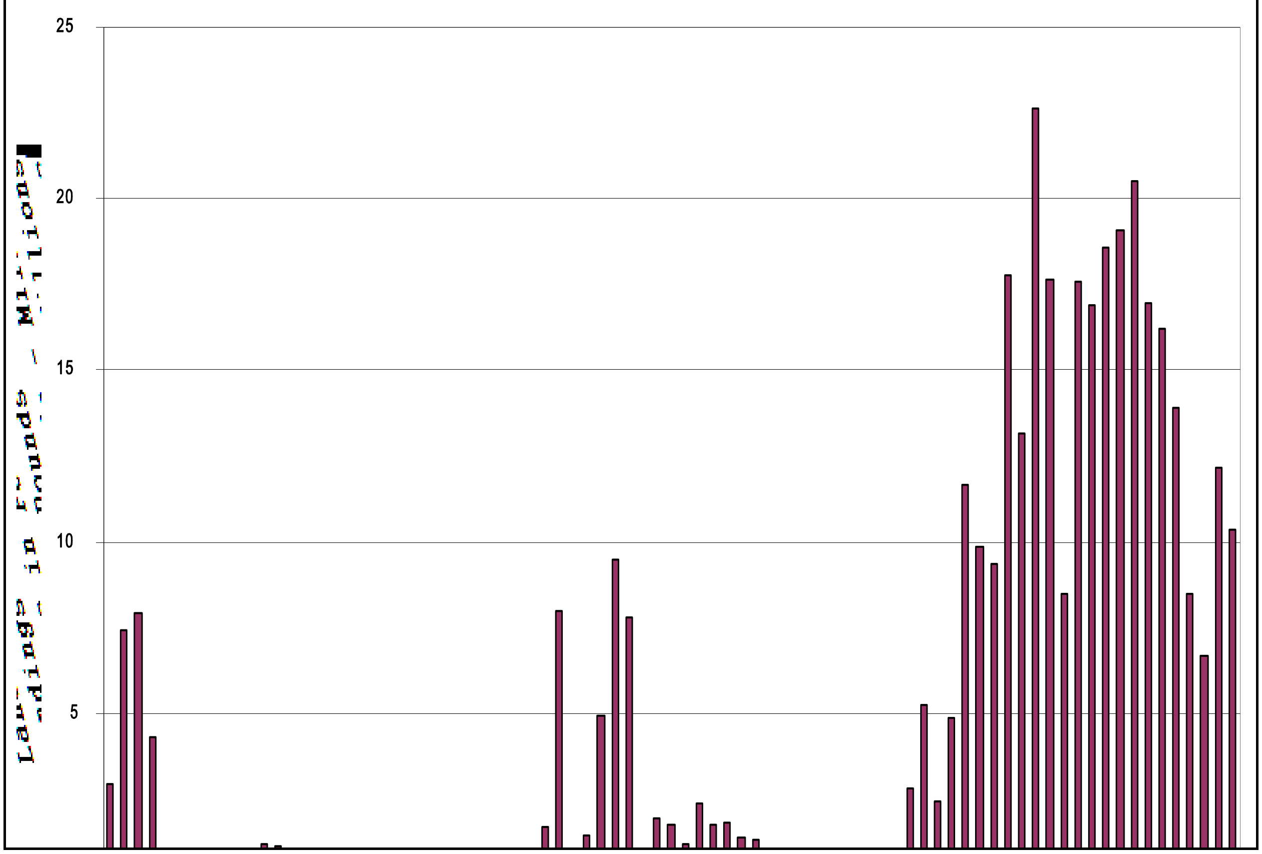
3.2.3 Human Use

Herring have been used by humans for a very long time. The Atlantic herring fishery is probably the oldest continuous fishery in the world (Obrebski and Hedgpeth 1984). The dominant product from herring fishing has varied considerably. Sac-roe, or mature egg skeins, which is used as a food product, is currently the dominant product on the west coast of the United States and Canada (Trumble and Humphreys 1985). Other uses of herring have included human food, bait for a variety of fisheries, animal food, and herring eggs-on-kelp. Herring eggs-on-kelp is a product of growing importance (Moore and Reilly 1989, Oda 1989). The dominant product from the Pacific herring fishery in California also has changed considerably through time.

3.2.3.1 Early Perspective

Pacific herring were commercially harvested in California before the turn of the century (Scofield 1918). There was a well established gill net fishery in San Francisco Bay in 1875. Continuous statistics on the State's fish landings have been kept since 1916 (Scofield 1952, Oliphant et al. 1990)(Figure 3.13).

Figure 3.13. Annual landings of Pacific herring in California.



Prior to 1916, most of the herring landed were consumed fresh but some were salted or smoked. As ocean sport fishing increased, more herring were used for bait. Landings for these uses have continued at low levels to the present day. Superimposed over this low level of use have been four peak periods when landings increased significantly.

During the four years 1916-1919 large quantities of herring were used for canning and for reduction into oil and meal. Most of these landings came from the Tomales Bay and San Francisco Bay areas. In the peak year 1918, the catch was about 8 million pounds. The California State Reduction Act of 1919 prohibited the reduction of whole fish of any species except by special permit. Permits were not issued to reduce herring, effectively ending the first period of peak landings.

During the 26-year period from 1920 through 1946, there was little or no canning of herring; but, moderate quantities continued to be sold for fresh consumption, for salting and smoking, and for bait. The second peak in landings began in 1947 in an effort to replace the sardine as a canned product. However, the product met with poor acceptance and landings declined by 1949 (Miller and Schmidtke 1956). The third peak followed shortly and lasted three years (1951-53). Some canning for human consumption continued and an unsuccessful effort was made to develop a pet food market for canned herring. Landings, primarily in the Monterey area, have continued at low levels to present; however, the herring are now used for bait and zoo animal food. The most recent peak in herring landings began in the early 1970's.

3.2.3.2 Recent Perspective

The most recent surge in landings started in 1973 when Japan began importing herring roe (egg skeins) from California. The herring egg skein is brined and sold as "Kazunoko", a delicacy in Japan (Spratt 1981). Annual landings increased rapidly, have exceeded 22 million pounds in recent years, and have averaged almost 15 million pounds since 1976 (Figure 3.13). The herring roe fishery starts in late fall and overlaps two calendar years. This results in two totals forherring landings, the annual herring landings and seasonal landings used for regulatory purposes (quota system).

Herring attain their highest economic value, based on roe content, just prior to spawning. This limits the roe fishery to the months of peak spawning activity (December through March). Spawning areas for herring in California occur in intertidal and shallow subtidal areas of protected bays and estuaries (Spratt 1981)(Figure 3.4). Only San Francisco Bay has a population large enough to support a major fishery. Small fisheries exist in the Tomales Bay area, Humboldt Bay and Crescent City Harbor.

Fishing technique has evolved somewhat in the herring roe fishery since its inception. Two gear types (gill nets and purse seines) have been primarily used in the herring roe fishery. Gill nets are single panels of net that are set (anchored) and left to capture herring by entanglement. Weights (along the bottom line) and floats (along the top line) hold the panel of webbing in a vertical position, to form a curtain-like wall of mesh. Purse seines are single panels of net that are rapidly laid out from a vessel and positioned to encircle herring. A small powered skiff aids in the encirclement process. Once encircled the bottom-weighted line is pursed to create a bag [Sec 4.2.6.1]. The bag volume is reduced by hauling the net onboard to concentrate the herring to the point where they can be tested for roe quality, and if acceptable, removed with a large scoop net or submersible pump. Fish of unacceptable quality are released. Beginning with the 1998-99 fishing season, gill nets will be the only gear used in the herring sac-roe fishery, following a regulation change which converts purse seine permits to gill net permits.

A small fishery also exists in San Francisco Bay that harvests Pacific herring eggs-on-kelp or "Kazunoko Kombu", for export markets (Moore and Reilly 1989, Oda 1989). Herring eggs-on-kelp, like herring roe, is a delicacy in Japan and is considerably higher in economic value. During the early phase in its development, the fishery harvested eggs spawned on naturally occurring algae in the bay (Spratt 1981). In 1985, giant kelp from the Channel Islands was used by suspending it from rafts anchored in likely spawning areas. This open pound eggs-on-kelp (ROK) fishing method is now exclusively used. Slightly over 106.8 tons of ROK from open pounds were landed during the 1995-96 season. This was equivalent to removing the spawning potential of 477 tons of herring for the season.

A herring dead bait and animal food fishery also contributes to current landings. This fishery occurs during the summer months with catches from Monterey Bay. Younger herring (1- and 2-yr-olds) are desired for bait and older herring are used for animal food. Peak landings of approximately 270 tons occurred in 1982.

3.2.4 Resource Management

The policy guiding the management of Pacific herring fisheries in California and the objectives of management are stated in the Fish and Game Code of California (Section 1700, Appendix 1). Briefly, the policy is to encourage the conservation, maintenance, and utilization of aquatic resources for the benefit of all the citizens of the State. The objectives of management under this policy include:

a. Maintaining sufficient populations to insure their continued existence.

b. Recognizing the importance of aesthetic, educational, scientific, and non-extractive recreational uses of the resource.

c. Maintaining sufficient resources to support a reasonable and satisfying sport use.

d. Promoting the growth of local commercial fisheries and use of unused resources when consistent with aesthetic, educational, scientific, and recreational uses.

e. Managing on the basis of adequate scientific information promptly promulgated for public scrutiny.

Management authority for regulating the herring roe fishery was initially in the control of the California State Legislature. During the first fishing season (1972-73), emergency legislative action (Fish and Game Code of California) established catch quotas for Tomales Bay and San Francisco Bay. The Legislature also established a herring fishery permit system.

The Legislature subsequently set catch quotas for the next season (1973-74), and included a catch quota for Humboldt Bay. Management authority for the Tomales and San Francisco Bay fisheries was then delegated to the Fish and Game Commission, including the authority to limit the number of herring permits. The Legislature also required the Commission to periodically review their regulations and policies.

The Commission has held the management authority for all herring fisheries in the State since 1976. A system has evolved to meet the legislative mandate to periodically review regulations and policies. The review occurs annually and is initiated when the Department presents its management recommendations based on stock assessments to the Director's Herring Advisory Committee. The Department's recommendations are modified, as necessary, based on the committee's comments and are presented at a public hearing. The recommendations are again modified, as necessary, and presented to the Fish and Game Commission. The recommendations and comments from the Department, other agencies, and the public are typically presented to the Commission at two meetings each year (June and August). The Commission subsequently adopts new regulations for the next fishing season (California Code of Regulations, Title 14. Natural Resources).

The Commission has available to it a variety of explicit regulations that can be introduced to achieve objectives identified in Section 1700, Fish and Game Code (Appendix 1). Several concepts new to commercial fisheries management in California have been introduced by either the Legislature or Commission to regulate the herring roe fishery, including: limited entry, 2) permits issued by lottery, 3) catch allocation by gear, and 4) individual vessel quotas. In general, the regulations either control the amount of fishing, control the composition of the catch, or control the allocation of the catch.

One of the most direct methods of controlling the amount of fishing is setting limits on total catch through a quota system. Many strategies have been developed by fishery scientists to set catch quotas. An objective of State policy is to regulate the catch from a commercial fishery at a level that is within the limits of maximum sustainable yield (MSY) to insure the continued existence of a harvested population. MSY is an estimate of the largest catch that can be taken continuously from a stock. The estimate is based on average characteristics of the stock computed over many years and on well established fishing practices. However, herring are known to undergo large fluctuations in stock size due largely to variations in annual recruitment. Average MSY harvest values can be excessive when recruitment has been poor and stocks are low. As a result, use of MSY is not the most appropriate strategy in formulating annual catch quotas in herring fisheries and is not used in California (Murphy 1977, Appendix 3).

A mathematical model (HMODEL) developed by the Pacific Fishery Management Council (PFMC) has been used to examine the long-term consequences of different harvest strategies for Pacific herring (Pacific Herring Fishery Management Plan - Draft, Appendix 3). The model, using selected biological characteristics of a stock, allowed comparisons of biomass, harvest levels, and stock stability over a long period for a series of harvest strategies.

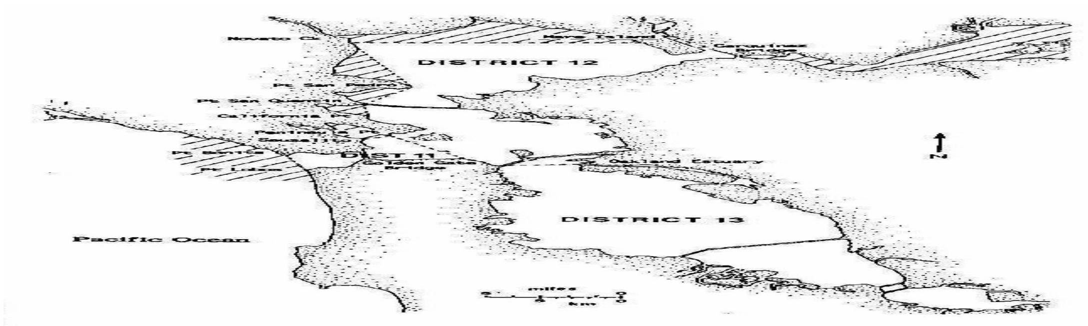
Several results emerged from the PFMC analysis that are germane to the selection of an alternative harvest strategy for Pacific herring in California. Two strategies were identified by the PFMC that maintained a long-term production even with strong fluctuations in stock size. One of these strategies is currently used by all Pacific coast states with herring fisheries, including California. The chosen strategy, discussed below, allows harvesting at a constant percentage of the estimated stock biomass. This strategy avoids excessive harvest rates that could occur under a constant tonnage (quota) approach and is more responsive to current stock and environmental conditions.

A range of constant harvest percentages were tested using HMODEL. At a harvest level of 20 percent and assuming a natural mortality of M = 0.4, the stock and harvest fluctuated, but did not decline during a 100-year simulation. At 40 percent, a long-term decrease occurred; but, the decline did not occur for over 25 years, indicating that heavy fishing pressure may be maintained if recruitment levels were high. The strategy of harvesting at a maximum of 20 percent of biomass was selected by the Department for use in California based on the above considerations.

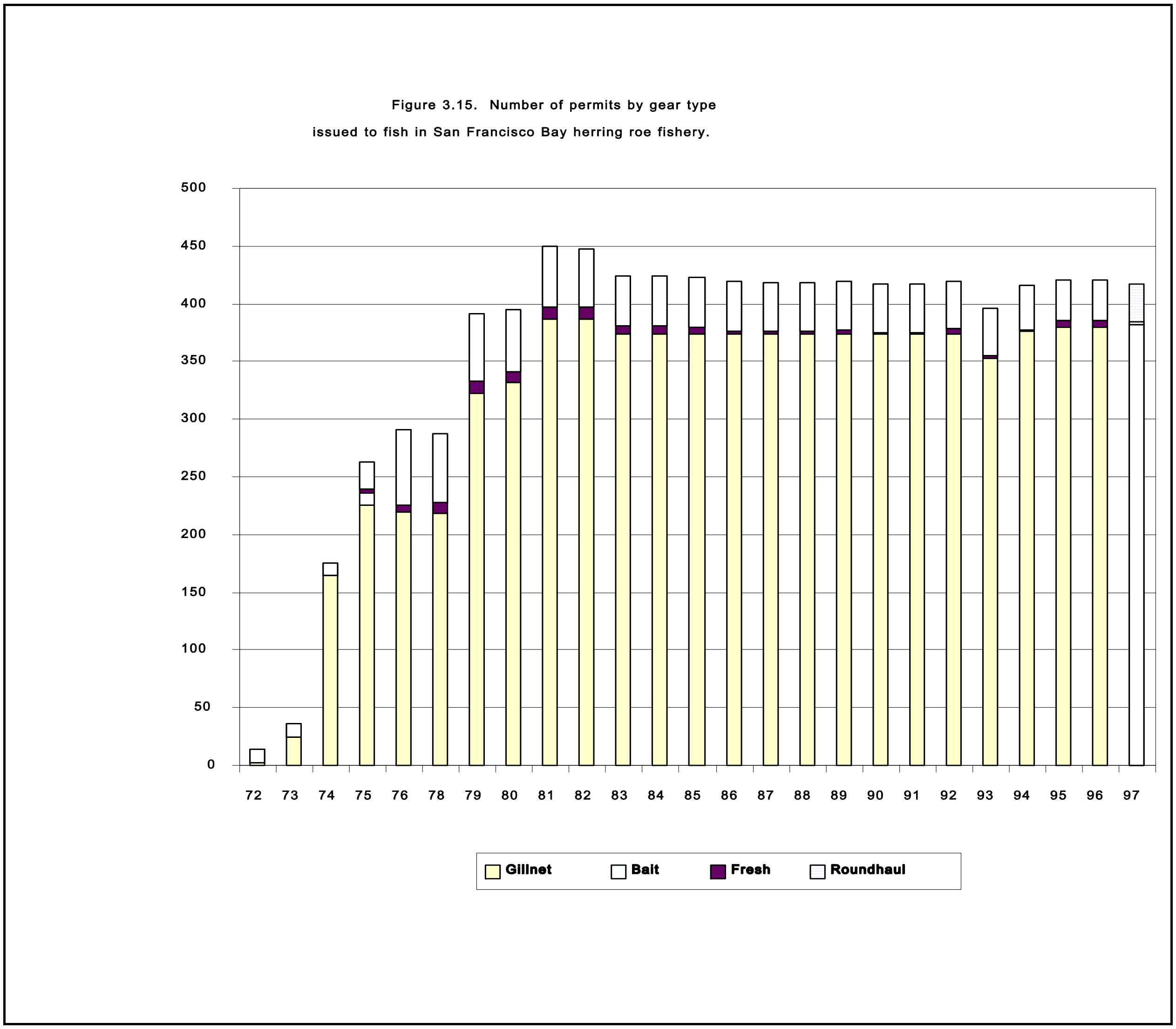
In addition to setting quotas based on biomass estimates, a variety of other regulations have been promulgated by the Commission as a result of their periodic review of existing regulations or as a result of additional guidance from the Legislature. Many of the changes have addressed socioeconomic issues. The proposed project (regulation of the commercial herring fisheries in California) has evolved, in large part, as a consequence of prior Commission action. The exact text of the most recent pertinent sections of the Fish and Game Code and Title 14 are provided in Appendix 1. A brief review of key management actions by geographical area follows.

3.2.4.1 Monterey Bay Area

Commercial herring fishing is restricted in open ocean areas to an area north of Yankee Point in Monterey county. Within this area fishing is further restricted to exclude those areas used for herring roe fishing (specific bays and estuaries). The total amount of fishing effort is not controlled other than stipulating that herring taken in open ocean waters may not be used for herring roe purposes. A season is set (April 1 to November 30) that excludes the typical spawning period.

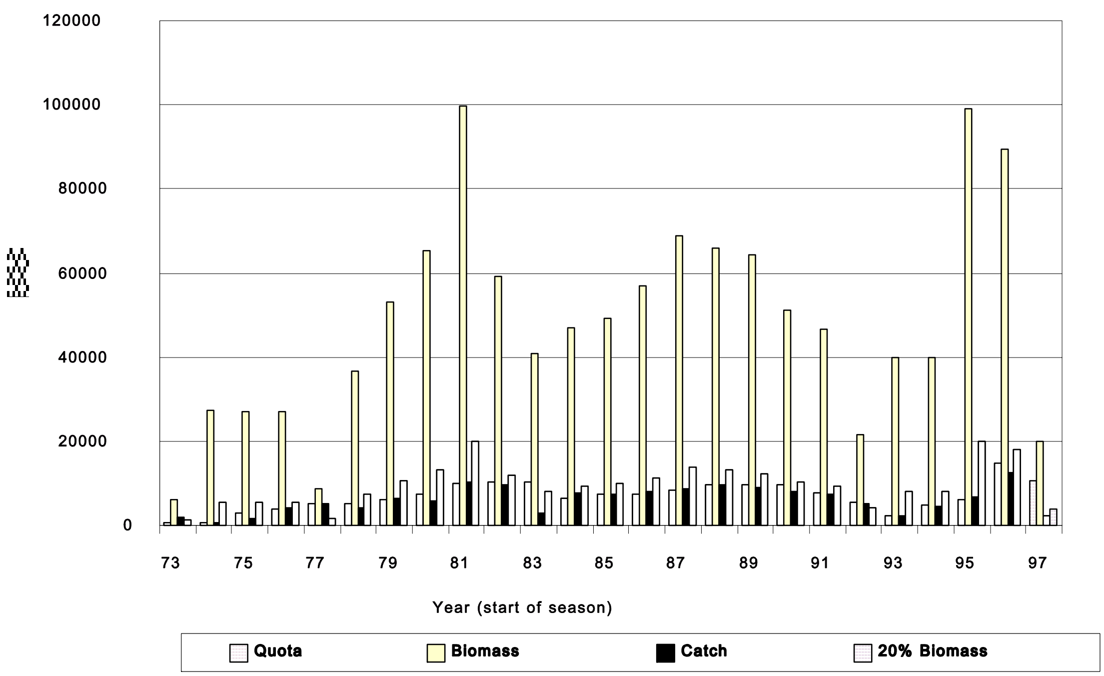


3.2.4.2 San Francisco Bay Area



Commercial herring fishing is restricted in San Francisco Bay to portions of San Pablo, Central, and South Bays (Fish and Game Districts 11, 12, and 13)(Figure 3.14). Within this broad area, fishing is further restricted in area through specific closures to selected fishing gears. The total amount of fishing effort in the San Francisco Bay herring fisheries has been controlled in two primary ways. Permits have limited the number of participants in the fishery and quotas have limited the catch. The number of permits and the quotas in San Francisco Bay both increased rapidly during the early phase of the herring roe fishery (Figure 3.15 and 3.16). The first significant increase in herring roe permits occurred during the 1976-77 season when a lottery for permits was discontinued and permits were issued to all qualified applicants. The majority of new permits issued at this and subsequent seasons went to gill net fishermen. The qualification criteria were tightened the next season by introducing a point system and fewer permits were issued. The next significant increase in the number of permits occurred during the 1980-81 season. Other than a few transfers from the Tomales Bay fishery during the next two seasons (1981-82 and 1982-83), an increase in the XH gill net platoon in 1982-83, and five new

Figure 3.16. Relationship between targeted catch (20% or less of spawning biomass) and actual catch - San Francisco Bay herring roe fishery.



permits

issued in the 1986-87 season, no additional permits have been issued in the San Francisco Bay herring roe fishery. The maximum number of permits active in any season was 430 (1982-83). Regulations have also evolved to establish qualification criteria for permits and to monitor the business aspects of procuring, selling and transferring permits.

Ten permittees are allowed to transfer into an eggs-on-kelp fishery. The quotas from their respective gear types and platoons were converted to an eggs-on-kelp quota.

Catch quotas are a primary tool for limiting total catch. They are based on Department recommendations and set by the Commission. Quota recommendations are based on no more than 20 percent of the previous season's spawning biomass, which is the closest possible estimate. A procedure has not been developed to provide a "real-time" (immediate) estimate of spawning biomass to set quotas in season [Sec 4.2.6.1]. Previous season spawning biomass may not accurately reflect stock size for the coming season. When biomass declines, a quota based on prior-season spawning biomass may be too high. The Commission can make in-season adjustments to quotas on an emergency basis, if necessary.

Gear restrictions and quota allocations have been enacted to reduce congestion on the San Francisco Bay fishing grounds and to control the rate of catch. Limiting the amount of gear helps achieve timely quota closures by improving the accuracy of landing projections. Congestion is also alleviated by dividing the permittees into platoons (Odd, Even, and DH) and assigning separate fishing periods and quotas.

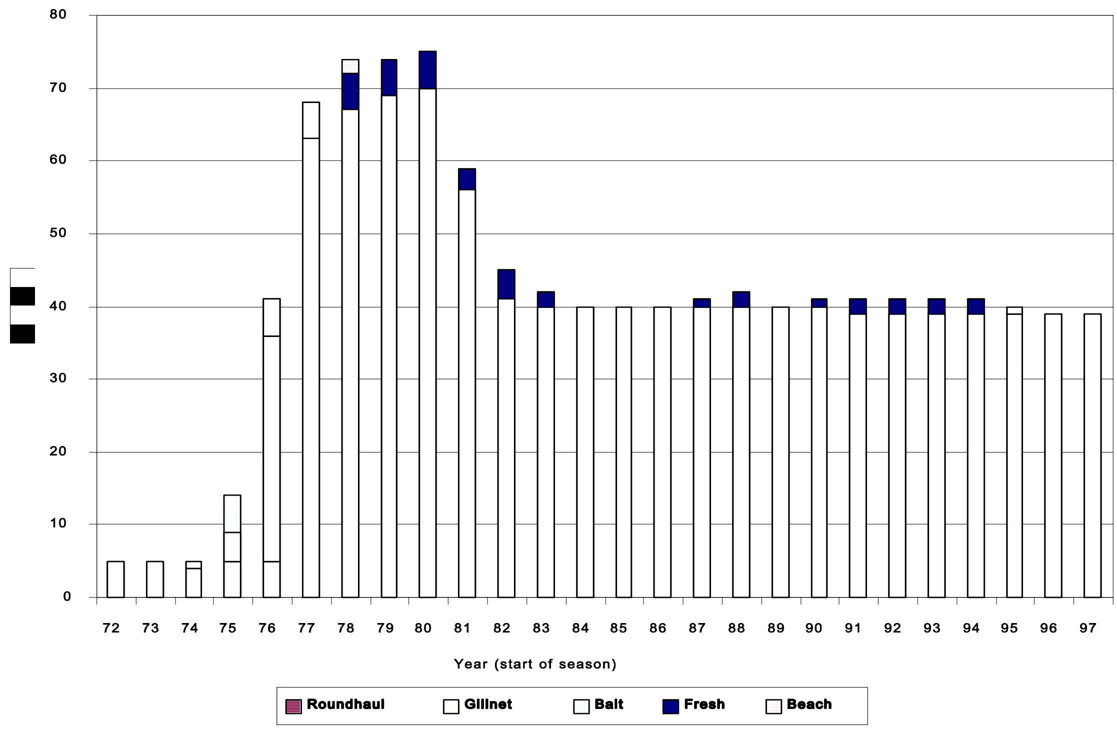
A variety of other management actions have been taken designed primarily to address social and economic issues. For example, closures, either in time or area, have been enacted to reduce gear conflicts, to minimize conflict with recreational uses of the Bay, and to address military concerns [Sec 4.2.7]. Closures have also been enacted to control noise pollution, to protect sensitive habitat, and to help insure safety [Sec 4.2.7].

3.2.4.3 Tomales Bay

Commercial herring fishing within the Tomales Bay has been limited in geographic extent to a small portion of Commercial Fishing District 10 (Figure 3.17).

Comparable actions to those used in the San Francisco Bay fishery have been taken to control the total amount of fishing in Tomales Bay (Tomales Bay discussion includes Bodega Bay). The number of permits issued increased rapidly as the fishery developed, peaking at 70 gill net permits in the 1980-81 season (Figure 3.18). Gill net permits accounted for most of the increase and have been the only permitted gear in this fishery since the 1980-81 season. The total declined to 40 permits during a two year period (1981-82 and 1982-83) when transfers were allowed into the San Francisco Bay fishery. No eggs-on-kelp fishery exists in these bays.

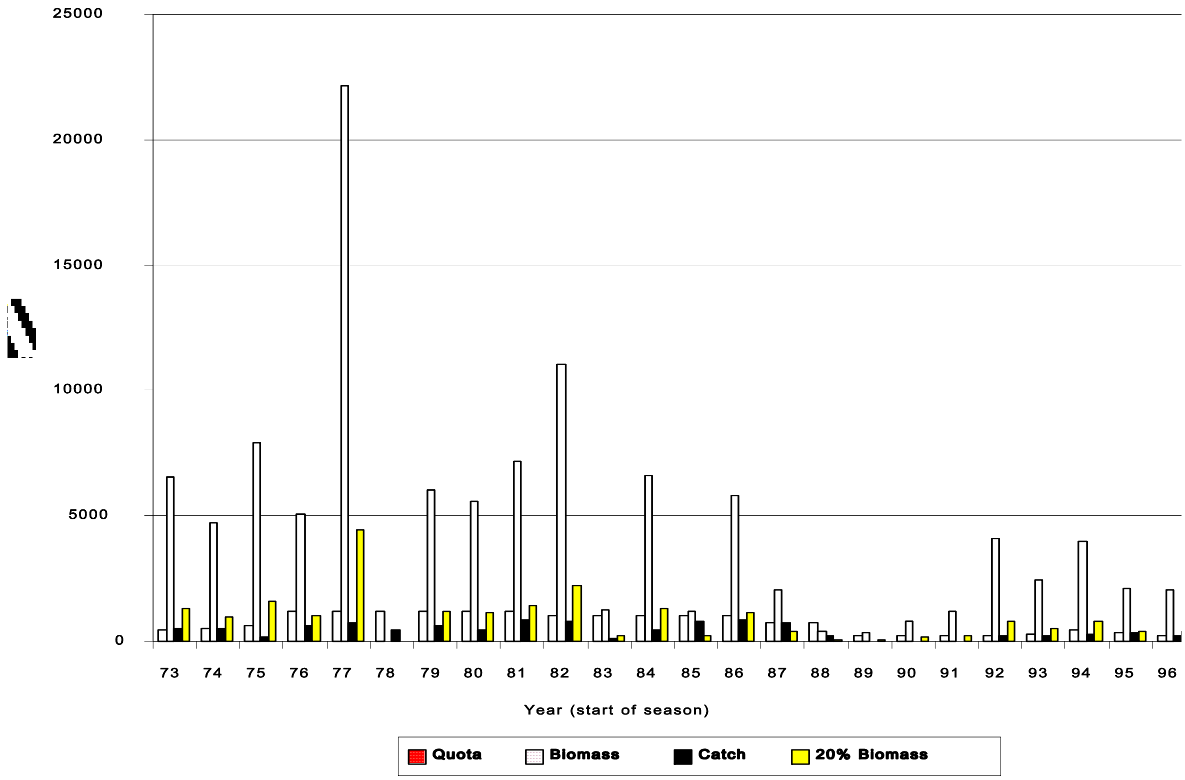
Figure 3.18. Number of permits by gear type issued to fish in Tomales Bay and Bodega Bay herring roe fishery.



The same general management strategy used elsewhere in California has been applied to setting quotas in Tomales Bay. Quotas were typically set closer to the allowable maximum (20 percent) (Figure 3.19). Quotas have fluctuated with biomass; the maximum quota allowed to date was 1210 tons. This is approximately 12 percent of the maximum allowed in the San Francisco Bay fishery.

Congestion and allocation issues have not been as prevalent in the Tomales Bay fishery. The use of round haul gear (purse seines and lampara nets) was precluded early in the fishery due largely to public sentiment. Platoons were initially created to reduce congestion when Tomales Bay and Bodega Bay permittees were grouped together; however, the platoon system is

Figure 3.19. Relationship between targeted catch (20% or less of spawning biomass) and actual catch - Tomales Bay.



not currently in use. Weekend closures minimize conflict with recreational uses of the Bay.

<u>3.2.4.4 Humboldt Bay and Crescent City Areas</u>

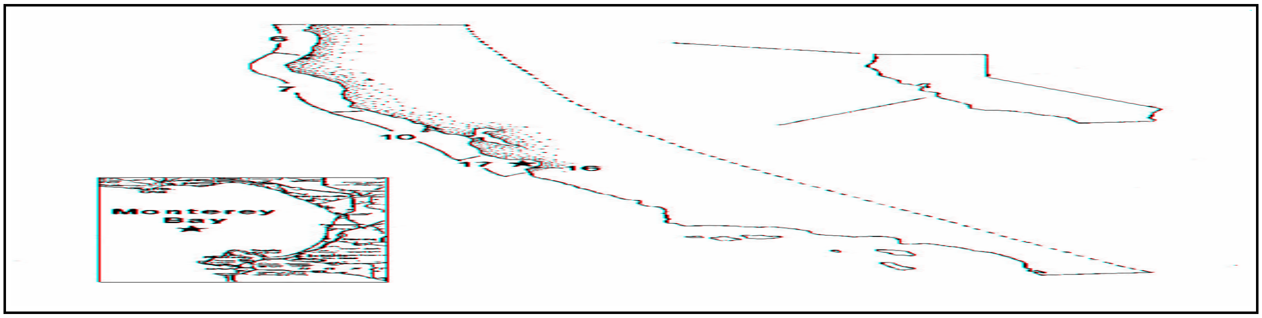
Commercial herring roe fishing is restricted to Fishing Districts 8 and 9 in Humboldt Bay and a small portion of District 6 in the Crescent City Area. Open-ocean fishing for herring (bait and animal food) is permitted offshore of both areas. However, the only commercial herring fishing in either area targets on herring roe. Permits and quotas are used to control the amount of fishing for herring roe as part of a statewide policy. A maximum of four permits have been issued for Humboldt Bay and three for the Crescent City Area. The number of permits has not changed since the 1977-78 season. Quotas for Humboldt Bay were adjusted from 20 ton to 50 tons during the 1976-77 spawning season as a result of biomass estimates obtained during the 1974-75 and 1975-76 spawning seasons (Rabin and Barnhart 1986) [Sec 4.2.6.1]. The quota was increased to 60 tons during the 1982-83 season. The catch has exceeded the quota on three occasions in both the Humboldt Bay fishery and the Crescent City Area fishery. Gill nets are used exclusively to take herring for roe in both areas. Weekend closures are not in effect in either area.

3.3 Specific Biological and Environmental Descriptions

3.3.1 Monterey Bay Area

3.3.1.1 Physical Environment

Although commercial herring fishing is permitted in ocean waters from Yankee Point (Monterey County) north to Oregon, the only existing ocean fishery is located within Monterey Bay (Figure 3.20). The description of the open ocean portion of the project area is restricted to the pelagic habitats occupied by herring. The pelagic habitat is a three-dimensional area composed of seawater which is influenced by ever-changing features such as sea-surface temperature, currents, and eddies, and provides a dynamic physical environment. Only the surface layer (surface to 150 meters) receives sufficient light to support plant growth. Plant populations (phytoplankton) in the surface layer provide food (primary production) to support organisms in the surface layer as well as in the deeper pelagic and bottom areas. Herring tend to occupy the neritic (overlying the continental shelf) portion of the pelagic zone.



Currents form one of the primary physical features of the ocean portion of the project area. The major alongshore currents off northern and central California coast are an offshore, southward flowing current (California Current) and a nearshore, northward flowing current (California Countercurrent).

The California Current system is a part of the huge clockwise circulation of the North Pacific Ocean. Near the coast of North America this flow divides into two branches. One moves south, becoming the California Current which eventually turns west merging with the Equatorial current. Superimposed upon the general southward flowing California Current are narrow, meandering bands of high velocity flow. The edges of the currents mix to create a series of eddies and swirls with occasional jets and filaments of water flowing offshore. The jet and eddy system can change substantially over short time scales (Mooers and Robinson 1984) and can have significant effects on water properties.

The nearshore northward-flowing California Countercurrent only reaches the surface when it is at its strongest in the fall and winter. At this point, it is generally called the Davidson Current (Hickey 1979). Northward flowing currents are warmer and typically poorer in nutrients.

During the summer, persistent northwesterly winds along the California coast blow the surface water southward and westward, covering the countercurrent. The surface water is replaced by cold nutrient-rich upwelled water. Upwelling is particularly strong along the coast in the vicinity of capes and submarine canyons. The commercial herring open-ocean fishery coincides with upwelling conditions and is generally restricted to the southern half of Monterey Bay, south of the large submarine canyon located in the middle of Monterey Bay.

Three distinct seasonal phases are present in the physical conditions of Monterey Bay waters, paralleling the phases observed on a larger scale. These are the upwelling period of summer, a calm warm "oceanic" period in fall, and the Davidson Current period in winter. In January and February, surface water temperature is relatively warm (13°C) with low salinity (33.2°/oo). As upwelling begins in spring, deep water rises, and the surface water cools and becomes more saline. Warming occurs in the fall, and the surface salinity decreases in winter (McLain and Thomas 1983).

Northwesterly air flows are the dominant pattern during the spring, summer, and autumn seasons. Wind speeds associated with the northwesterly-type flow pattern range from 2 to 7 mi/hr during the morning and evening hours and from 8 to 16 mi/hr during the afternoon. A variety of flow patterns exist associated with the movement of winter storms through the area.

3.3.1.2 Biological Resources

The biological component of the pelagic habitat in the Monterey Bay area is composed of organisms from northern subarctic areas mixed with organisms from southern transition areas. Phytoplankton populations are dominated by diatoms with other less conspicuous seasonal components. There is also some seasonality and patchiness in zooplankton abundance, dominated by the presence of crustaceans (copepods and euphausiids) and arrow worms (chaetognaths).

The primary consumers within the pelagic community are schooling fishes. Northern anchovy, Pacific and jack mackerel, Pacific sardine, and Pacific herring are the most abundant species in this group. The market squid, an invertebrate, occupies the same general niche and is also an important food source for higher trophic level feeders.

Fluctuations in the strength of the California counter-current have had notable effects on the distribution and abundance of various marine organisms. Of particular interest is the impact of major El Niño warming events. Phytoplankton and zooplankton characteristic of low latitudes become more prominent in the warm years (Garrison 1979). However, both plankton communities are typically depressed during warming events leading to changes throughout the food web. These fluctuations can have significant influences on the abundance and distribution of species that occupy higher trophic levels.

A number of marine birds may feed on herring in ocean waters; included are the shearwaters, cormorants, common murre, auklets, puffins, marbled murrelet, and brown pelican. The availability of herring as prey for many bird species is dependent on herring vertical migrations, bringing herring into shallow surface waters where they are accessible as prey.

A number of marine mammals are known to prey on pelagic schooling fish in the open ocean. Among the marine mammals that may feed on herring in the Monterey area are the California sea lion, the northern elephant seal, Steller sea lion, and the northern fur seal. All of the smaller cetaceans are likely to be herring predators. Among the larger cetaceans, Minke whales, humpback whales, and fin whales are known to be fish eaters. The remaining large whales may consume herring incidentally. This group includes the California gray whale in some areas. However, the California gray whale does not typically eat during its migrations through California waters.

Threatened or endangered species found within this region include the brown pelican

(Pelecanus occidentalis californicus), southern sea otter (*Enhydra lutris nereis*), marbled murrelet (*Brachyramphus marmoratus*), and the Steller sea lion (*Eumetopias jubatus*). The brown pelican is state and federally listed as endangered; the sea otter is federally listed as threatened; the marbled murrelet is state listed as endangered and federally listed as threatened; and the Steller sea lion is federally listed as threatened**.**

The brown pelican is found in the area during seasonal migrations. Brown pelicans tend to follow their primary prey, the anchovy. Anchovy abundance increases in the Monterey Bay area during the fall, and decreases in late winter when fish move offshore and to the southeast to spawn. Sea otters are year-round residents of the Bay, occupying near-shore kelp beds and feeding on a variety of shellfish. The marbled murrelet, another coastal resident species, nests inland and feeds on inshore marine fishes including Pacific sandlance, anchovy, and Pacific herring (Burkett 1995). The Steller sea lion occurs occasionally in transit through Monterey Bay. This species breeds to the north of Monterey Bay at Año Nuevo and is a likely consumer of herring in addition to other fish species.

3.3.1.3 Socioeconomic Environment

Regional Economy:

The area used to characterize the regional economy is Monterey County. The 1990 population estimate for the county is 360,200 (California Statistical Abstracts 1990). Over 35 percent of the population lives in the immediate vicinity of the Monterey peninsula.

The county is a leading producer of vegetable crops (ranked first in the State) with over 65 percent of land dedicated to farms. Between 1988 and 1991, unemployment levels ranged from 8.1% to 10.9% (Employment Development Department 1992).

Commercial Fisheries:

A number of commercial fisheries operate in or near the Monterey Bay area. Included among these are several that occur in the same area where herring are taken and that use the same vessels (squid, mackerel, anchovy, and sardine fisheries). Commercial salmon trolling also occurs in the same general area on a seasonal basis. Of significant economic value to the fishing industry in the area is the bottom trawl fishery operating offshore of typical herring habitat. This fishery targets on Dover sole, thornyheads, rockfishes, lingcod, and other groundfish.

Commercial fishery support facilities are located in the Monterey harbor, in Moss Landing, and in Santa Cruz harbor. Most of the activity mentioned within this section operates from the Monterey harbor.

Commercial Shipping:

Very little commercial shipping occurs in the immediate vicinity of Monterey. Tankers do use moorings outside of Moss Landing to offload fuel for use in power generation at the Moss Landing Pacific Gas and Electric Company facility.

Recreation:

Recreational uses of the nearshore waters in the Monterey Bay area include fishing for salmon, halibut, rockfishes, and lingcod. The nearshore waters along the peninsula are also heavily utilized by the sport diving community, kayakers, motor boaters, and sailing enthusiasts.

3.3.2 San Francisco Bay Area

3.3.2.1 Physical Environment

San Francisco Bay is a natural estuary which is separated from the Pacific Ocean by an approximately one mile wide natural opening called the Golden Gate. San Francisco Bay is situated on the central California coast about 400 miles (640 km) north of Los Angeles. The Bay is characterized by broad shallows carved by narrow channels whose depths are maintained by swiftly moving currents. The average depth of the Bay is 20 feet (6 m) with a maximum depth of 360 feet (110 m) in the Golden Gate area.

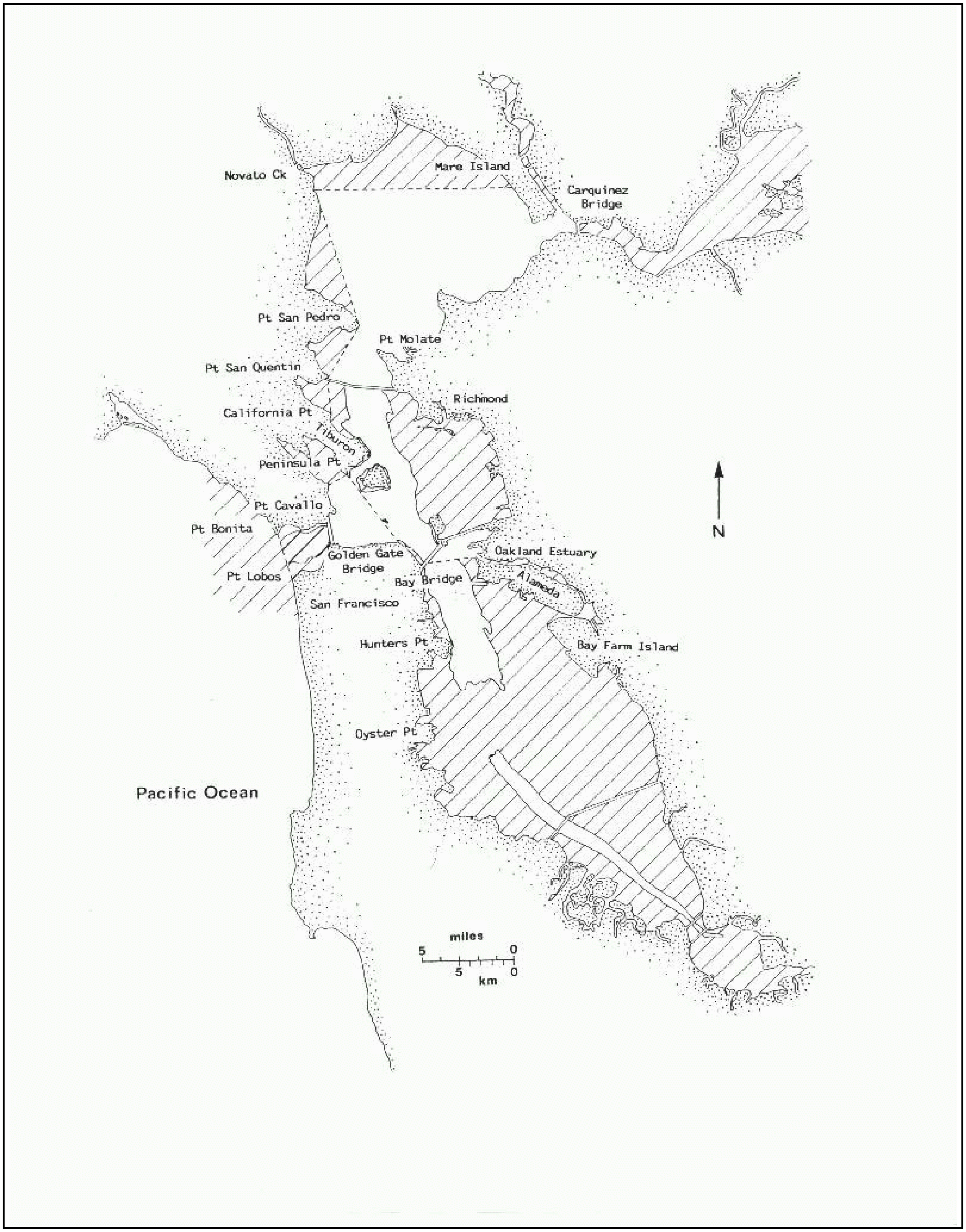
There are at least four distinct reaches (areas) within San Francisco Bay: 1) Suisun Bay, 2) San Pablo Bay, 3) Central Bay, and 4) South Bay. Commercial herring fishing is presently permitted within portions of all reaches except Suisun Bay (Figure 3.21). The primary fresh water inflow into San Francisco Bay is into Suisun and San Pablo Bays from the Sacramento and San Joaquin Rivers. The Sacramento and San Joaquin drainage basin encompasses approximately 40 percent of the State of California. It is estimated that ten million cubic yards of sediment move into San Francisco Bay annually from these sources and other natural runoff (Krone 1966).

Tidal velocities within the Bay determine the distribution of particles from this sediment load. The coarser sediments may be found near the estuary mouth (Golden Gate), with fine-grained muds being deposited on the flat, shallow bottom areas in most of the Bay. Channel beds

dominated by large-grained particles, especially coarse sands. The particles are constantly being resuspended, transported, and redeposited by water movement. Water movement is dominated by a two-layered circulation pattern that results from opposition of freshwater outflows and tidal inundations of seawater. Higher outflows result in more rapid net circulation and more intensive mixing of water masses. Wind stress-caused turbulence also mixes the fresh and seawater layers.

Tidal amplitude is another major driving force in estuarine circulation. During strong spring tides, total water exchange with the Pacific Ocean may be as much as 24 percent of the total volume of the Bay in a single tidal cycle (Herrgesell et al. 1983).

The principal factors that influence air quality in the area are mixing height and wind speeds. The mixing height is the height of the top of the air layer in which relatively vigorous vertical mixing occurs. Mixing height is usually lower in the morning than in the afternoon. In the San Francisco Bay area, morning mixing heights range from 1300 to 2300 ft and afternoon mixing heights range from 2100 to 3500 ft (Holzworth 1972).



Northwesterly air flows are the dominant pattern during the spring, summer, and autumnseasons. Wind speeds associated with the northwesterly type flow pattern range from 2 to 7 mi/hr during the morning and evening hours and from 8 to 16 mi/hr during the afternoon. A variety of flow patterns exist associated with the movement of winter storms through the area.

Because the prevailing winds blow off the Pacific Ocean, the air quality in San Francisco is among the least degraded of all the developed portions of the Bay Area. The primary air quality problems are levels of carbon monoxide (CO) and total suspended solids (TSP). The primary source of CO is motor vehicles. The primary sources of TSP's are demolition, construction activities, and motor vehicle travel over paved roads. Motor vehicles also contribute significantly to ozone production through the emissions of hydrocarbons and nitrogen oxide.

The latest emission inventory (1996) for the San Francisco Bay area was extracted from the Bay Area Air Quality Management District (Toch Manget, pers. comm.)

3.3.2.2 Biological Resources

The Bay supports a diverse assemblage of organisms. Each reach of the Bay is a distinct habitat area characterized by different salinity regimes and by different biota. The estuarine species are most concentrated in the northern bays and the marine species are more abundant in the South and Central Bay.

Generally, turbid bay water reduces the area suitable for attached and rooted plant growth to very shallow waters and marsh areas. These plant forms are important at particular locations, but phytoplankton are more important to the total Bay productivity. Diatoms, a type of phytoplankton, represent a substantial portion of the total plant production in the Bay. Phytoplankton production is concentrated in the large shallow areas where light readily penetrates. Peak abundance of phytoplankton typically occurs during the spring and abundance is greatest in the Central Bay area.

The bottom community in Suisun and San Pablo Bay is dominated by the Asian clam, an introduced species that has reached densities >10,000 m^2 in some areas (Hymanson 1991). Since late 1986, both the number of species and the number of individuals of species other than the Asian clam have declined. The percentage contribution of the Asian clam to total abundance in this portion of San Francisco Bay has reached 95 percent. Concurrently, the abundance of the common estuarine copepod (zooplankton) in the upper estuary has declined >90 percent (Kimmerer et al. unpub. manus.) and the summer phytoplankton bloom in the upper estuary has disappeared since 1987 (Alpine and Cloern 1992). These are dramatic changes in the bays ecosystem and are attributed to grazing by the Asian clam. The Asian clam is also well established south of the Dumbarton Bridge and is spreading southerly and westerly in the south bay (L. Schemel USGS, Menlo Park pers. commun.). The Asian clam may represent a major link in the benthic-pelagic coupling of the San Francisco Bay estuary.

Dominant mobile invertebrates (animals without backbones) in the San Pablo Bay area include the bay shrimp and the Dungeness crab. Bay shrimp spawning occurs in more saline areas of the Bay but juveniles migrate to shallower, lower salinity regions after larval settling. The Dungeness crab is present in the Bay only as last-stage larvae and juveniles. The larvae move into the Bay during April and May. Young-of-the-year spend about one year growing in the Bay before returning to the ocean.

The bottom community in the Central and South Bay areas is more diverse. The Japanese cockle, the bent-nosed clam, and the Atlantic soft-shell clam are dominant clams in these areas. The bay shrimp is joined by a related species in the more marine environment typical of Central and South Bay. The Dungeness crab is also found in both reaches of the bay.

A variety of vertebrate (animals with backbones) consumers are supported by the estuary. Some estuarine fish are resident species, completing their entire life cycle within the estuary. The most common estuarine fish include the plainfin midshipman, topsmelt, jacksmelt, bay pipefish, shiner surfperch, yellowfin goby, prickly sculpin, and Pacific staghorn sculpin. Marine species tend to use the Bay seasonally as a spawning ground or nursery area. Coastal species that commonly occur in the Bay include several species of sharks and rays, smelts, surfperch, rockfish, gobies, sculpin, white croaker, starry flounder, California halibut, and English sole, as well as the northern anchovy and Pacific herring.

The estuary also serves as an acclimation zone, facilitating the physiological changes necessary for anadromous fish to make the transition between salt water and fresh water. Anadromous fish may pass through the estuary only during spawning and out migrations (salmon and steelhead) or reside in the estuary for longer periods (sturgeon, American shad, longfin smelt, three-spined stickleback, and striped bass).

A large variety of water-associated birds use the San Francisco Bay estuary. They include waterfowl, shorebirds, gulls and terns, seabirds, raptors, wading birds, and song birds. The heaviest use of the Bay by shorebirds and waterfowl comes during the spring and fall migrations; however, many also remain during the winter. Gulls are most numerous during the winter months, while terns are more commonly seen in summer months. Ducks, grebes and other water-associated birds are primarily winter visitors to the Bay. Other groups may be found year-round.

The San Francisco Bay estuary has a significant role in supporting ducks and shorebirds during their winter residency. Approximately 23 percent of the diving ducks in the Pacific Flyway (migration pathway) winter in San Francisco Bay. They arrive in the Bay area about mid-October and may remain in the area for 6 to 8 months each year, feeding primarily on small clams and snails. The most numerous diving ducks are canvasback, scaup, scoter, and ruddy ducks.

Sea lions and harbor seals are commonly found in many areas of the Bay. Harbor seals are resident in the Bay year-round, while sea lion abundance is greatest in winter during the non-breeding season. This provides the opportunity to feed on schools of herring that peak in abundance in the Bay during the same time frame.

Several endangered animal species are known to dwell or have potential to dwell in the vicinity of the project area. California least terns, *Sterna antillarum browni* nest in the Alameda area and forage in nearby waters. The California least tern is listed as endangered by both State and Federal agencies. The least tern is a fish-eating bird, capturing small fish in its bill by diving into the water from low flight. The majority of its diet consists of four types of fish: the northern anchovy, silversides, surfperch, and to a lesser extent, the Pacific herring (Bailey 1985). It appears that tern foraging distribution and intensity may be linked to the availability and distribution of forage fish. The breeding and nesting season in the San Francisco area occurs between May and September. This colony is the largest north of San Luis Obispo with the number of nests ranging from 40 to almost 75.

The California brown pelican (*Pelecanus occidentalis californicus*) is also listed as endangered by both State and Federal government agencies. It uses open water areas of the Central and South Bay for feeding, and rocks, jetties, and piers for roosting. This use is concentrated in the summer months after breeding in southern California, but also occurs during winter months when Pacific herring are spawning in the Bay. Open-ocean food habit studies have shown that anchovy comprise a large part of the California brown pelican's diet; however, Pacific saury and rockfish have also been observed. Pacific herring in bay waters can be found near the surface, particularly during spawning, and should be considered as likely prey.

The Sacramento river winter-run king salmon have recently been designated as a threatened species by the Federal government (PFMC 1990). Winter-run king salmon enter the estuary in October enroute to spawn in the Sacramento River. Offspring of winter-run king salmon move rapidly downstream in the fall. Downstream migrants feed primarily on insects and marine crustaceans; however, small fish are also a component in their diet.

3.3.2.3 Socioeconomic Environment

Regional Economy:

Geographically, the Bay Area extends south to San Mateo and Santa Clara counties, north to Marin and Sonoma counties, and east through Napa and Solano counties. The central region, which is the location of the fisheries regulated by the proposed project, includes San Francisco, Marin, and San Mateo counties to the west and Alameda County to the east.

The nine-county Bay Area represents one standard consolidated statistical area and is the fifth largest metropolitan area in the country. As of 1995, the Bay Area had a total population of 6,394,300 (ABAG 1997).

The diverse employment profile in the Bay Area is the reason for the growth and resistance to recessionary trends. San Francisco is the central hub of the Bay Area. It contains the headquarters for the Bay Area government, financial, and planning sectors. The majority of jobs in San Francisco , approximately 33.1 percent (Employment Development Department 1989), are in the service industry. The newest and fastest growing sector of the Bay Area economy is the high-technology industry. Also known as the Silicon Valley, Santa Clara County is home to several hundred high-technology firms.

The employment diversity within the Bay Area has resulted in unemployment rates below state and national average. In 1990, the unemployment rate for the nine Bay Area counties was 5.2 percent while the statewide rate was 6.6 percent and the national rate was 6.3 percent (Association of Bay Area Governments, 1990). All of the counties in the Bay Area reported unemployment rates below six percent in 1990, with most of the unemployment rates below five percent (Employment Development Department 1992).

Commercial Fisheries:

Currently, the major commercial fishery within San Francisco Bay waters is for Pacific herring. A California halibut hook-and-line fishery occurs in the Bay during the spring and summer months. Bay shrimp and anchovy support bait fisheries in the Bay. During the 1993-94 season, 13 bay shrimp permittees were active (i.e. landed bay shrimp). One commercial concern fishes for anchovy within San Francisco Bay. The remaining commercial activities are on a very small scale and are entirely hook-and-line activities.

The San Francisco Bay area is one of the State's largest landing ports for marine resources. Approximately ten fish businesses buy herring within San Francisco Bay each season. Last season nine of these were located along the San Francisco waterfront, and one was located in Sausalito.

Commercial Shipping:

San Francisco Bay is an important area for the commercial shipping industry. The ports along the Bay serve as primary import-export centers. The Bay serves 25 military installations, 11 of which use the Bay for transport. The Bay is also used by commuting and sightseeing ferries, and recreational, maintenance, and service vessels such as tugboats.

Commercial use of the Bay represents 98 percent of all Bay traffic and 88 percent of this traffic remains in the Bay. The commercial traffic consists of tugboats with tow, tugboats without tow, and ferries. The remaining 12 percent of the commercial traffic enters and leaves the Bay through the Golden Gate. In 1987, there were 83,073 recorded vessel movements in San Francisco Bay (U.S. Navy 1988).

Recreation:

White and green sturgeon, striped bass, chinook salmon, American shad, California halibut, starry flounder, jacksmelt, white croaker, brown rockfish, sevengill shark, leopard shark, brown smoothhound shark, bat rays, staghorn sculpin, herring, and various surfperch support recreational fisheries in the San Francisco Bay estuary.

South, Central, and San Pablo Bays are used for recreational boating. A large portion of that use is for sailing and tends to occur during the weekend.

3.3.3 Tomales Bay Area

3.3.3.1 Physical Environment

Tomales Bay (Figure 3.17) is located approximately 40 miles north of San Francisco. The Bay occupies the northern end of the San Andreas Rift between the Point Reyes Peninsula and the rest of the coast. The San Andreas fault separates the Tomales Bay region into two distinctive geologic areas. The west side of the Bay is bordered by steep slopes of granitic rock on Point Reyes. The east side is comprised of a mixture of rock types consisting mainly of sandstones, with minor amounts of other material (shale, undifferentiated basaltic rock, conglomerate). The Bay encompasses an area of 11 square miles, is 13 miles long and slightly over 1 mile wide at its widest.

The tides in Tomales Bay are semi-diurnal. Two unequal low tides and two unequal high tides occur in each 25-hour period. Because of the long, narrow shape of the Bay, tidal incursion has a time lag of about one hour from the entrance to the back bay. Maximum tidal range during spring tides can be over 8 ft. As a result, the tidal flux of sea water into the Bay is about 50 percent of the Bay's total volume. Even though the Bay does not completely flush with each tidal cycle, it is a well-mixed water body dominated by tidal flow.

The flushing action in the Bay has been affected by the damming of inflowing streams. Without large inflows the Bay acts as an effective nutrient trap, with increased algal blooms and eutrophication. Drainage into Tomales Bay is primarily from two sources: the largest is from the Lagunitas Creek system, followed by the Walker Creek drainage system. Both of these streams supply most of the continental sediment that enters the Bay. Tidal flats are extensive in Tomales Bay. Most of the sandflats occur near the mouth of the bay. Sand is initially supplied to the bay entrance by southerly longshore currents in Bodega Bay. The most extensive mudflats are located in the upper bay. Rocky shoreline, found primarily on the western side of the Bay, is not extensive

.3.3.3.2 Biological Resources

The habitats found in Tomales Bay support a diverse fauna. In many regards, the plants, fish, birds, and marine mammals found in Tomales Bay are comparable to those found in San Francisco Bay. Eel grass beds are more extensive, as are clam beds (gaper clam, Washington clam, and geoduck) found in soft bottom areas dominated by silty-sands.

Threatened and endangered species found in the waters of Tomales Bay are the California brown pelican and the marbled murrelet. Brown pelicans utilize Tomales Bay for feeding and roosting as described for San Francisco Bay [Sec. 3.3.2.2]. The marbled murrelet is a coastal resident species which feeds on inshore fishes including Pacific herring, anchovies, and sandlance

(Burkett 1995). The Steller sea lion may occasionally visit Tomales Bay; although it typically utilizes outer coast areas, hauling out on rugged offshore rocks.

3.3.3.3 Socioeconomic Environment

Regional Economy:

Tomales Bay is located in Marin County. Statistical summaries for the county are used to characterize the regional economy. The county's population in 1990 was 237,000. Only a small portion of that population (26 percent) lived in the unincorporated areas of Marin County including the towns of Tomales and Bodega Bay (Sonoma County). Over 50 percent of the land in the county is devoted to farms, with an emphasis in livestock production. The unemployment rate was the second lowest for any county in California in 1987 (3.2 percent) and the per capita income was the highest in the State.

Commercial Fisheries:

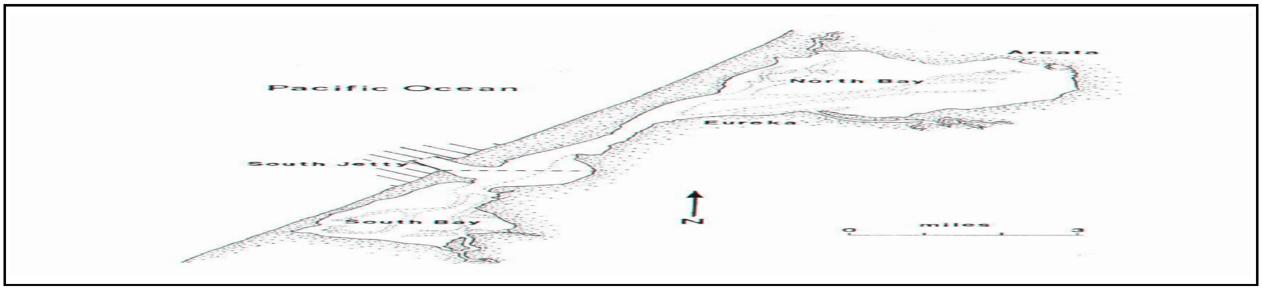
Commercial fisheries operating within Tomales Bay include a minor surfperch fishery occurring primarily during spring, a year-round small bait fishery for mud and ghost shrimp, a small late spring through summer troll fishery for California halibut, and oyster and clam mariculture which occurs throughout most of the Bay.

Commercial Shipping:

No large commercial shipping occurs in the immediate vicinity of the Tomales Bay and Bodega Bay area. The area cannot handle deep-draft shipping and offshore mooring is not present.

Recreation:

Sport fisheries exist for bay clams (primarily gaper and Washington clams) in both Tomales Bay and Bodega Bay. Use of Tomales Bay can be extensive during the lowest tides of



the year. Nearshore coastal sport fisheries exist for salmon, California halibut, Dungeness crab, rock crab, abalone, and rockfish. Salmon are caught by trolling. Rockfish and halibut are also taken using hook-and-line gear. Dungeness and rock crab are taken using small traps. Much of the nearshore sport fishing effort occurs within the Bodega Bay area.

3.3.4 Humboldt Bay Area

3.3.4.1 Physical Environment

Humboldt Bay is located approximately 200 miles north of San Francisco. The herring roe fishery is restricted to Humboldt Bay waters (Figure 3.22). Excluding its tributary sloughs the bay is about 25 square miles in size, with freshwater inflows from a 288 square mile drainage basin. The main tributary streams are: Jacoby Creek, Freshwater Creek, Elk River, and Salmon Creek. The bay is 14 miles long and 4.5 miles wide at its widest point. Humboldt Bay is essentially a lagoon created by the presence of a long baymouth bar sand spit. During extreme high tides and high seas, the surf often passes over the low dunes directly into the Bay. The Bay consists of two wide, shallow northern and southern arms connected by a relatively narrow channel, that connects the Bay to the ocean. Both Bay segments are extremely shallow with large mud flats exposed at low tide. Tidal channels average 25 feet in depth near the Bay mouth and decrease in depth in the Bay's upper reaches.

Water currents determine the pattern of the tidal channels and the character of bottom sediments.

Higher velocity water prohibits the settling out and accumulation of mud within the channels. Sand is coarse near the inlet and along the main channel and becomes finer and is mixed with some silt and clay farther into the Bay. Low intertidal flats are composed mostly of silt with some sand and clay, while high flats are primarily clay with some silt. Generally, the pattern of sediment distribution is one of decreasing particle size with increasing elevation and distance from the bay mouth.

3.3.4.2 Biological Resources

Both phytoplankton (microscopic freely floating plants) and eel grass (rooted plants) are important in Humboldt Bay's primary production. Eel grass beds are located on the broad low mudflats in both Bay segments. These mudflats also support a rich shallow infauna (invertebrates within six inches of the surface). The species and numbers present depends to a large extent on the sediment composition and location. The Bay is also an important nursery area for Dungeness crab and English sole.

The higher forms (fish, birds, mammals) utilizing the Bay are, to a large extent, similar to those described for San Francisco and Tomales Bays [Sec. 3.3.2 and 3.3.3]. Anadromous fish use of the Bay is limited because the inflow streams are small and limited. Migratory and resident waterfowl, shorebird and wading bird use of the Bay is significant due to the presence of large mudflats and abundant eel grass beds.

Threatened and endangered species that use Humboldt Bay include the brown pelican, and marbled murrelet. Their use of the Bay and its resources is similar to that described for Monterey Bay [Sec. 3.3.1.2] and Tomales Bay [Sec. 3.3.3.2]. The Steller sea lion is probably an infrequent visitor to Humboldt Bay due to its tendency to utilize the open coast rather than bays and estuaries.

3.3.4.3 Socioeconomic Environment

Regional Economy:

Statistical summaries from Humboldt County are used to characterize the regional economy. The population base in the county is small compared to more southerly counties with herring roe fisheries. The 1990 county population estimate was 120,300. Roughly 33 percent of the population live in Eureka and Arcata; both cities are located along the edge of Humboldt Bay. Approximately 27 percent of the county area was devoted to farming in 1987. Timber harvest and wood products provide the leading source of income in the county. Humboldt County was the leader in timber harvest during 1987. Unemployment during the same period was moderate compared to counties statewide (7.5 percent).

Commercial Fisheries:

The herring roe fishery and oyster culture are the only significant commercial fishing activities to occur within Humboldt Bay. Oyster culture uses the north bay almost exclusively yielding the bulk of the State's oyster production. Offshore commercial activities include a large trawl fishery targeting on Dover sole, a variety of other flatfish, widow rockfish, thornyheads, and sablefish. The area supports a large salmon troll fishery, a shrimp trawl fishery targeting on Pacific ocean shrimp, and a Dungeness crab trap fishery.

Commercial fishing is considered to be a major industry in the area, along with agriculture, tourism, and wood products. The commercial fish landings in Humboldt Bay were greater than those of any other California port north of Los Angeles in 1989. Harbor and service facilities that support the local commercial fishing fleet are found at Fields Landing, King Salmon, and the Eureka waterfront. Several processing plants are located on the Bay.

Commercial Shipping:

The commercial shipping industry exists primarily to meet the demand for transportation of saw logs, lumber, and paperpulp. Docking facilities for ocean-going cargo vessels are located on the Samoa Spit, Fields Landing and the south Eureka waterfront.

Recreation:

A wide variety of water based recreational activities exist in Humboldt Bay. These activities include waterfowl hunting (a large percentage of the total State black brant kill occurs in Humboldt Bay), angler sport fishing (primarily shore fishing), and clamming. Other uses include nature study, wildlife observation, and photography.

3.3.5 Crescent City Area

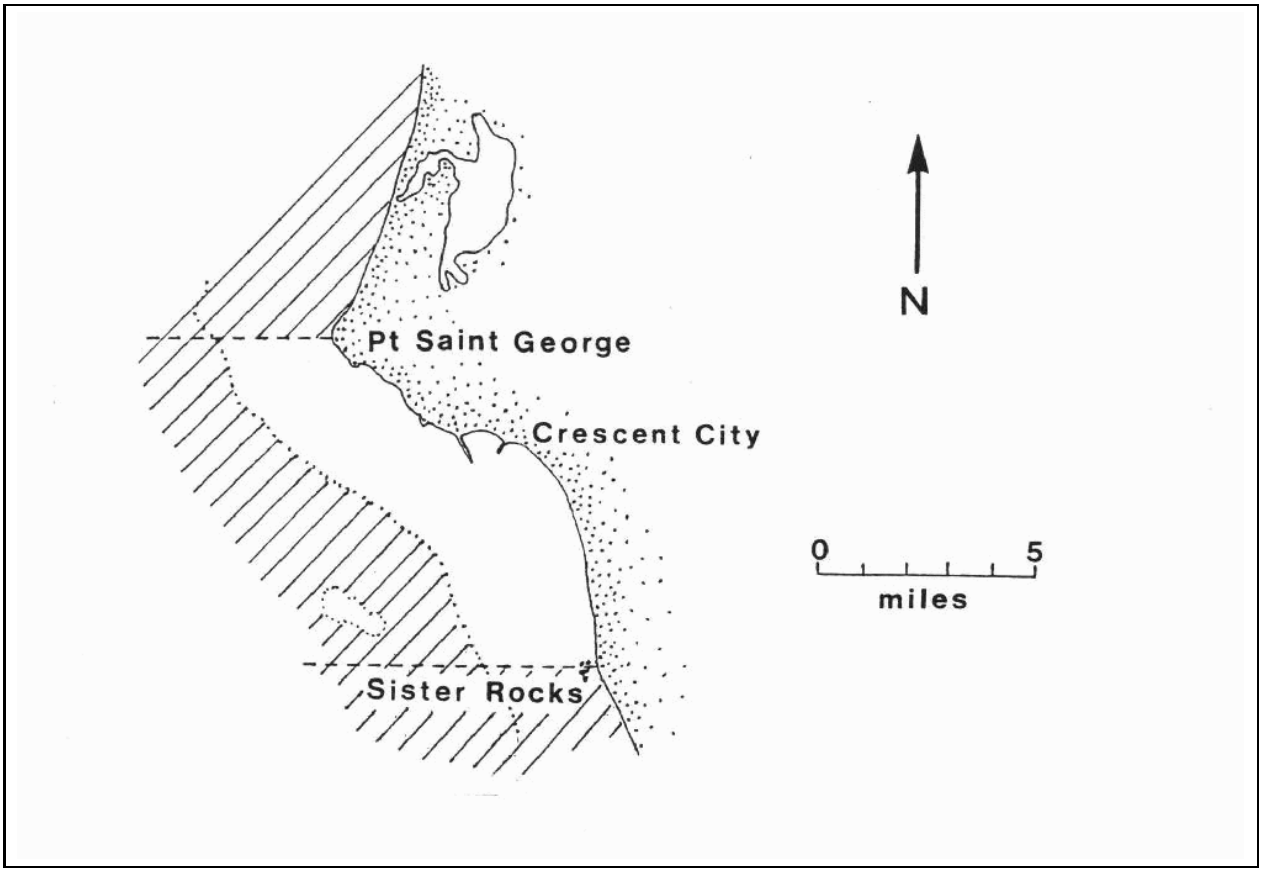
3.3.5.1 Physical Environment

The Crescent City area is approximately 15 miles south of the Oregon - California border. Approximately 11 miles of coastal waters south of Point Saint George and Crescent City harbor are open to commercial herring roe fishing (Figure 3.23). Beaches in the area are of limited distribution along the otherwise rocky coast. This section of open pelagic habitat has the same general characteristics described for the open ocean fishery [Sec 3.3.1.1].

3.3.5.2 Biological Resources

Biological resources in the area have also been characterized in the section describing the open ocean fishery [Sec 3.3.1.2]. The Dungeness crab and Pacific Ocean shrimp populations are bottom or near bottom dwellers in the northern portions of ocean waters open to herring roe fishing that were not mentioned in the section focusing on Monterey Bay.

Threatened or endangered species that use Crescent City area waters include the brown pelican, marbled murrelet, and Steller sea lion. Their use of this area is similar to that described for Monterey Bay [Sec. 3.3.1.2.].



3.3.5.3 Socioeconomic Environment

Regional Economy:

Statistical summaries from Del Norte County are used to characterize the regional economy. The population base in the county is the smallest for all counties supporting commercial herring fisheries. The 1990 county population estimate was 22,250. Almost 20 percent of the population lived in the Crescent City area. Only 2 percent of the county land was devoted to farming in 1987. Timber harvest levels were the fourth largest in the State. Unemployment, at 11.8 percent was the second highest in the State.

Commercial Fisheries:

The offshore fishery for Pacific Ocean shrimp and Dungeness crab are larger in the Crescent City area than they are in regions to the south. Large landings of Pacific whiting are also a feature of commercial fisheries activity that set the Crescent City area apart. Trawl landings of Dover sole, thornyhead, sablefish, and widow rockfish are made in the Crescent City area. Salmon trolling for both king and silver salmon also constitutes a significant part of the commercial catch in the area.

Commercial Shipping:

No large commercial shipping occurs in the immediate vicinity of the Crescent City area. The area cannot handle deep-draft shipping, and offshore mooring is not present.

Recreation:

Water orientated recreational activities in the area used by commercial herring roe fishery are similar to those described for nearshore recreational activities in the Humboldt Bay area. Nearshore recreational activities are directed primarily toward fishing. Species of interest include salmon, Pacific halibut, redtail surfperch, rockfish, lingcod, albacore, and Dungeness crab.